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# PRACTICAL TREATISE

ON

# MECHANICAL ENGINEERING,

COMPRISING

METALLURGY, MOULDING, CASTING, FORGING, TOOLS, WORKSHOP MACHINERY, MECHANICAL MANIPULATION, MANUFACTURE OF THE STEAM-ENGINE, ETC.

WITH

## AN APPENDIX

## ON THE ANALYSIS OF IRON AND IRON ORES.

BY

FRANCIS CAMPIN, C.E.

PRESIDENT OF THE CIVIL AND MECHANICAL ENGINEERS' SOCIETY, AUTHOR OF "THE ENGINEER'S POCKET REMEMBRANCER FOR CIVIL AND MECHANICAL ENGINEERS," ETC., ETC.

TO WHICH ARE ADDED

OBSERVATIONS ON THE CONSTRUCTION OF STEAM-BOILERS, REMARKS UPON FURNACES USED FOR SMOKE PREVENTION AND ON EXPLOSIONS.

BY ROBERT ARMSTRONG, C.E.

REVISED, WITH NOTES, BY JOHN BOURNE.

RULES FOR CALCULATING THE CHANGE WHEELS FOR SCREWS ON A TURNING LATHE, AND FOR A WHEEL-CUTTING MACHINE,

BY J. LA NICCA.

HE MANAGEMENT OF STEEL, INCLUDING FORGING, HARDENING, TEMPERING, ANNEALING, SHRINKING, EXPANSION, AND THE CASE-HARDENING OF IRON,

BY GEORGE EDE.

ILLUSTRATED WITH TWENTY-NINE PLATES OF
ILERS, STEAM-ENGINES, WORKSHOP MACHINERY, CHANGE WHEELS FOR SCREWS, ETC., AND ONE HUNDRED WOOD ENGRAVINGS.

PHILADELPHIA:
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1864.

# Dedication.

TO

THOMAS WICKSTEED, Esq.,

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS,
HONORARY MEMBER OF THE ROYAL POLYTECHNIC SOCIETY OF CORNWALL.
ETC., ETC.

THIS WORK

Is Respectfully Dedicated,

IN GRATEFUL ACKNOWLEDGMENT OF NUMEROUS KINDNESSES RECEIVED

FROM HIM

BY HIS OBEDIENT SERVANT,

THE AUTHOR.

# PREFACE.

The peculiar character of the volume now submitted to the scientific world imperatively demands a full account of the views which have led the author to adopt the system of arrangement pursued in the following pages.

The great number of works hitherto published on the various branches of mechanical engineering may generally be classed under two heads—viz., elementary works, describing the general principles and forms of steam-engines, and complete treatises, including detailed descriptions, scientific disquisitions, and rules for calculating the proportions of various machines; the latter class also occasionally touching upon manufactures. There appeared, however, to be a very obvious chasm in the literature of mechanical engineering, some treatise being required possessing the following qualifications:

Practical method, portability, conciseness, and the exclusion of all unnecessary matter; the subject-matter comprising all the general operations connected with mechanical engineering, the scientific principles and examples illustrating the present condition of mechanical engineering. In the hope, therefore, of supplying to practical engineers and to students such a work the present treatise has been written.

The account of the processes which constitute the manufacture of iron commences with an introduction setting forth the natural condition of the minerals from which the metals of commerce

are derived, and enumerating the operations conducted in the factory.

In the first chapter, the metallurgy of iron, copper, lead, tin, and zinc is considered; the nature and localities of the various metalliferous ores being described, and also the practical methods most usually employed for the reduction of metals to the conditions in which they occur in commerce; the apparatus required, and the principles upon which their action depends, and the mode of working them being also included.

Then follows a description of the various processes of forging and of the instruments used by the smiths. After which the construction of patterns, the methods of forming moulds of various kinds, and of casting metals, are discussed.

The form and action of the cutting-tools of the engineer have been carefully detailed, a thorough knowledge of the requirements which must be satisfied, in order to secure their correct action, being most important, though a proper appreciation of the forms of the principal machine tools is scarcely less necessary; wherefore some sound examples of turning-lathes, shaping, slotting, drilling, planing, and other machines, have been illustrated and described. As a sequel to the foregoing descriptions, an account of workshop manipulation is given, so far as it admits of description.

The physical basis of the steam-engine is next considered, the more refined methods of analysis being avoided, so as to retain a strictly practical character. Dr. Joule's equivalent for the calculation of the amount of work to be obtained from a given quantity of heat is inserted, forming, as it does, a convenient means for the *expression* of quantities of heat. But it is derived from experiments upon the amount of heat generated by friction of liquids; and, therefore, the author does not feel justified in considering its application to thermo-motive engines demonstrated, the facts extant being insufficient for this purpose. Stimer's and Isherwood's

experiments on the practical utility of using steam expansively have also been discussed at some length.

In the chapter on the Principles of Mechanical Construction, an attempt has been made so to generalize the theory of the action of levers, hydrostatic presses, &c., as to replace by a simple calculation, easily remembered and applied, the numerous rules and formulæ which have hitherto been so abundantly supplied for levers, divided into various orders, and for other machinery, and which, being generally given without any notice of the reasoning upon which they are based, cannot be remembered, and frequently serve but to confuse the reader. The laws of falling bodies of rotatory motion, &c., are also explained.

The general forms of steam-engines, and principles of steam-boilers, and qualifications of various kinds of engines are briefly treated, followed by lengthy accounts of the form and manufacture of each principal element of the steam-engine, after which the form, action, and manufacture of various kinds of pumps and valves are treated.

Practical formulæ for the length of boilers, descriptions of various kinds of boilers, and of the modes of constructing them, also accounts of the paddle-wheel, screw, and hydraulic propellers, with miscellaneous remarks upon some of the applications of steam-power, have also received due attention; and particular stress is laid upon the necessity of having reliable experiments upon steam-engines, and attention is drawn to the inferiority of modern engines in point of economy. It is indeed a fact much to be regretted, that notwithstanding the researches of scientific men, and the labors of practical engineers, no improvements have been made in the economy of the steam-engine since 1845. The remainder of the work is occupied by descriptions of examples of pumping, rotative, marine, locomotive, traction, and steam fire-engines, concluding with a Glossary of the technical terms used throughout the work.

As in the account of the metallurgy of iron notice has been taken of the effects of various foreign ingredients with which the iron of commerce is always more or less contaminated, it has been thought advisable to add an Appendix, containing the various methods of analyzing chemically the various ores of iron and specimens of iron, so as to enable those who may feel disposed to examine for themselves such samples as may come under their notice.

The examples of the machinery illustrated have been carefully selected, and every means taken to secure correctness of the Plates.

The thanks of the Author are due to many scientific gentlemen who have assisted him with plans and information; especially to Thomas Wicksteed, Esq., for the plans of the large pumping-engine at the Grand Junction Water-works, designed by him in 1845; the Bolton-and-Watt pumping-engine at the East London Water-works, erected in 1829; Cornish boiler now erecting at the Scarborough Water-works; also for valuable information concerning the above, and the new pumping-engine now erecting at the Scarborough Water-works. To C. G. Gumpel, Esq., for plans of his hydraulic propeller, information concerning the same, and experiments performed for the Author's information upon the same. Also to Messrs. Pullan and Lake for plans of their new patent agricultural locomotive, and for the information respecting the same and their new traction engine.

WESTMINSTER,
*January*, 1863.

# PREFACE

## TO THE AMERICAN EDITION.

WITH a view to add to the usefulness of Campin's valuable treatise on PRACTICAL MECHANICAL ENGINEERING, the American publisher has added to it:

"Observations on the Construction of Steam-Boilers; Remarks upon Furnaces used for Smoke Prevention, and on Explosions." By Robert Armstrong, C. E. Revised, with Notes, by John Bourne. "Rules for Calculating the Change Wheels for Screws on a Turning Lathe, and for a Wheel-cutting Machine." By J. La Nioca. And "The Management of Steel, including Forging, Hardening, Tempering, Annealing, Shrinking, and Expansion, and the Case-hardening of Iron." By George Ede.

In its present form, he feels quite confident that it will prove to be one of the most important additions to the literature of Practical Mechanics ever made within the limits of a single volume in the United States.

PHILADELPHIA,
*November* 2, 1863.

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## INTRODUCTION.

In the following pages we purpose to treat of the various processes and manipulations which the materials employed in the construction of steam-engines and other machinery must undergo before the complete machine can be produced. We think it desirable, before proceeding with a practical description of these processes and manipulations, to give a brief account of the order in which they occur, and of the ends which they are intended to fulfil, to enable us subsequently to treat each branch of the iron manufacture without touching upon collateral operations.

Iron, in common with the other metals generally used for mechanical purposes, does not occur pure in nature, but is invariably combined with other substances, from some or all of which it must be freed before it is fit for the purposes of commerce. In order to remove these foreign ingredients from the ores or minerals in which the various metals occur, sundry chemical and mechanical processes are required. In the first instance, it is necessary to remove the excess of argillaceous matrix with which many ores are contaminated. Some are subsequently roasted, to expel moisture, &c.; after which the ores may be smelted, in order to obtain in a state of greater or less purity,—according to circumstances,—the metals contained in them. This process of smelting is of a chemical character, and consists principally, in the case of iron, in depriving the metallic oxide of its oxygen, which is effected by means of carbon at a high temperature, which has a greater affinity for that element than has the ferruginous material. In the case,

however, of ores consisting of metallic sulphides, a somewhat different course is requisite, as will be hereafter explained.

After smelting, iron is usually obtained as cast-iron, which, when bar-iron is required, must undergo some further purification. We may here pause to explain the physical and chemical distinctions existing between cast and wrought-iron. Cast-iron contains many impurities, consisting principally of silicon, manganese, carbon, sulphur, phosphorus, aluminium, and sometimes traces of copper, arsenic, and other foreign metals. Most of these elements may be removed by oxidation in the form of slag, and in the removal of the impurities chiefly consists the conversion of cast-iron into wrought-iron; and the process may be conducted by exposing a large surface of the heated metal to the oxidizing influence of the atmospheric air.

Another material which we must here mention is steel. This consists of nearly pure iron, combined with a small portion of carbon, and perhaps of nitrogen also. The subject of the action of nitrogen in the production of acieration, as the conversion of iron into steel is termed, is a point upon which there has recently been much discussion, and some very interesting experiments by MM. Caron and Fremy. The latter has found that by exposing pure iron at a high temperature to the action of ammonia, nitrogen is thereby absorbed, which enables the metal subsequently to take up a portion of carbon from certain carburetted gases. This effect, however, is not well accounted for, as it is not by any means proved that cyanogen is formed during the operation; we must, therefore, for the present, content ourselves with the fact that steel is thus produced, waiting for further experiment to explain the theory of its production.

It is not to be expected that a quantity of foreign elements will exist alloyed or combined with a metal, without producing a very marked change in its physical properties; and thus we find that cast-iron is very widely different in its nature from wrought-iron. Cast-iron is granular, brittle, rigid, elastic, and offers but little resistance to tensile force, although it well withstands compression; whereas, on the other hand, wrought-iron is fibrous, tough, flexible, offers great resistance to tensile force, but not so much to compressive force. These are the general characteristics of the two materials; but various specimens of them exhibit different degrees

of strength, according to their composition. Phosphorus, sulphur, and silicon appear to be highly injurious; whereas titanium, nickel, and perhaps manganese, exert a contrary action. Steel, besides possessing in a high degree the qualities of wrought-iron, when in a soft state, admits also of being raised to various degrees of hardness. The processes of hardening and tempering are very simple, and are thus conducted:—The steel to be hardened, having been raised to a red-heat, is plunged into water, or other cooling medium, whereby a very great state of hardness is obtained. The fracture is then crystalline. Steel in this condition is unfit for the generality of purposes, and therefore requires to be tempered previous to use; to effect this, it is gradually heated, becoming the softer the higher the temperature to which it is raised; the proper point of temper is ascertained by the color exhibited by a film of oxide, which forms on the exterior of the metal. This color is probably produced by the interference of light, which is caused by a ray of light striking the upper surface of the film, a part of it being immediately reflected, whilst another portion passes through the film with refraction, and is reflected from its lower surface, when, if the film be thin, it frequently happens that some of the component rays reflected from the lower surface interfere with and neutralize some of those previously reflected from the upper surface. Steel works for various purposes are thus with certainty prepared with the proper temper: for coach-springs and similar articles, it is tempered to a blue tint; for small springs, such as the spiral and blade springs made in the smaller machinery, the metal is raised to such a heat as will impart to it a pale-blue tint; for cutting-tools, the color is straw-yellow, varying in shade according to the manner in which the tool is to be used.

We must now offer a few remarks upon the other materials with which, subsequently, we shall have to deal. Copper, as used in commerce, is prepared in a state of comparative purity; but the processes required for its reduction are exceedingly complicated, five or six operations in reverberatory furnaces being necessary for the reduction of sulphide of copper. The metal is ductile, but requires, when being worked, to be frequently annealed; it may be wrought under the hammer cold, but works better at a slight elevation of temperature. It has been found that the addition

of a small quantity of phosphorus materially improves the strength of copper; for although this element is so detrimental to iron, yet when it is combined with copper in the proportion of two to four per cent., it imparts to that metal considerable hardness and tenacity; its tensile resistance then becoming about four-fifths of that of ordinary iron, or two-thirds of that of the Low-Moor iron-plates. Alloys of copper with aluminium have the advantage of homogeneity and tenacity; but from the fact that aluminium is powerfully affected by alkaline substances, its use is for many purposes precluded. Copper, when combined with about four per cent. of silicon, possesses the hardness of steel and the tenacity of wrought-iron, and if this alloy could be manufactured on a large scale with convenience, it would doubtless be found applicable to a great variety of purposes. It may be interesting here to mention the method of combining the phosphorus and copper, as advised by F. A. Abel, Esq., Director of the Chemical Establishment of the War Department. The phosphorus should be coated with copper by immersing the pieces in a solution of sulphate of copper; after which process they may be handled with perfect safety, and when they are thrown into the molten metal, the external film of copper will efficiently protect them from oxidation during the very short period required for combination. One of the most important alloys of copper is brass, though gun-metal is perhaps almost as extensive in its applications. The strength, however, of brass is not by any means equal to that of the phosphorus and copper alloy.

The metals, tin, lead, and zinc, will also demand some consideration, but it is unnecessary here to comment farther upon them.

Having concluded our introductory remarks upon the earlier processes of metallurgy, we may proceed to mention the branch of manufacture of which we purpose next to treat. This includes the forging of metal both by hand and by steam-power; and also the various methods of reducing the materials to the required size and form. In this section we shall also refer to the formation of wood-patterns, as the models from which castings are usually made are called. In this part we shall most particularly explain the construction and method of using the tools and machinery with which the workmen must be provided, in order accurately to execute the manipulations with which they are engaged.

Our next subject will comprise the theory or principles upon

which the construction of the steam-engine generally is based, as also that of other machinery; but we shall not seek here to enter into very elaborate arguments or demonstrations, but rather to explain in the simplest and most succinct manner well-established facts, with which it is important for every practical man to be acquainted. We shall also include in this section simple rules for proportioning the various parts of machinery.

The remainder of the work will be occupied with descriptions of the various forms of steam-engines usually applied to manufacturing, marine, and locomotive purposes.

We will now conclude these brief introductory remarks, which may be regarded as an account of the branches of manipulative science which we purpose discussing, and proceed with the detailed consideration of the same.

## CHAPTER I.

### ON METALLURGY.

BEFORE proceeding with a description of the processes employed in the metallurgy of iron, it is necessary to enumerate the minerals from which it is usually obtained. Those which contain at least twenty per cent. of metal are usually considered ores, but if they contain less they are regarded as fluxes, the use of which in metallurgical operations will subsequently be indicated. Ores of iron are very widely disseminated, being found as beds in the sedimentary rocks, or as veins and massive deposits in the older formations, in which position the most valuable ores are obtained. They frequently occur beneath the coal-measures, which arrangement is exceedingly convenient, the fuel for the manufacture being found on the same spot with the ferruginous minerals. In some of the North American States, and in other places, magnetic iron-sand occurs in the drift at the foot of mountain-ranges, and bog-iron ores are also occasionally found in a similar position. In the cretaceous system, large deposits of ferruginous sand occur, but on account of their low yield they have never been extensively worked. Below the cretaceous system there are some extensive deposits of iron, which were formerly worked in Hampshire and Sussex, the metals being reduced by charcoal supplied from the neighboring forests; these are, however, at the present day neglected. In Northamptonshire and the Cleveland district of North Yorkshire are found beds of oolitic iron-ore, sometimes of a thickness of twenty feet, and affording in many instances thirty-three per cent. of metal. A few thin beds occurring in the lias formation have been partly worked in Lincolnshire and Yorkshire, but they are not rich in metal; in this formation, magnetic iron-sand and small portions of hematite also occur. The iron-works of this country, however, are supplied principally from the earthy carbonates of the coal-measures, from which excellent metal is obtained.

The coal-fields of South Wales, Staffordshire, Yorkshire, Scotland, North Wales, Shropshire, and Warwickshire, contain abundant deposits of this ore.

When the iron ores have been raised to the surface, the first operation consists in the cleansing of them. The earthy carbonates of the coal formations are placed in heaps, and left for several months, after which it will be found that the excess of adhering clay-shale has become separated by the action of the atmosphere, leaving the ores clean and fit for the furnace. The oolitic ores and the magnetic oxides and rich hematites of foreign countries are frequently cleansed by making use of the superior specific gravity of the ferruginous portion of the products; but in England the hematites undergo no other preparation than a partial hand-picking to separate large masses of refuse matter. We may now explain the theory of the reduction of iron. If an oxide of iron be highly heated in contact with carbon, the latter, having a greater affinity than the former for oxygen, takes it from the ferruginous oxide, thereby eliminating the metal. It is, however, necessary to provide some substance readily fusible, in order to dissolve certain impurities; such substances are called fluxes. They should be incapable of holding in solution any considerable quantity of iron. Chalk forms an excellent flux, but limestone is the cheapest material, and therefore most frequently employed. It may be interesting here to insert a list of the ores, fuels, and fluxes used in some of the principal works of Great Britain. At the Whitehaven foundry, hematite ore of a very pure character is employed, and is reduced by means of a mixture of Newcastle coke and coke manufactured at the works as fuel, with Whitehaven limestone and black shale, consisting of clay and carbonaceous matter, as fluxes. A sample of this ore when dried contained sixty-nine per cent. of metallic iron, generally pure, containing a large amount of silicon. At the South-Bank furnaces an earthy carbonate of iron with silicate is used containing thirty-five per cent. of metal, with a hard variety of coke as fuel, and dark-gray limestone for flux. At the Butterley works, blue-rake and brown-rake ores are used, the latter containing about thirty per cent. of metal; Brand's hard coal is the fuel, and Bullbridge or Crawford limestone the flux. At Lay's iron-works, a mixture of various ores is employed; the fuel is a mixture of Durham and Derbyshire Thickbone cokes, with Frog-

hall and Dudley limestone as flux. At the Heyford iron-works ochrey-brown ironstone, containing about thirty-nine per cent. of metal, is reduced by coke prepared from the coal of the South-Yorkshire Railway Company, fluxed with limestone consisting of an agglomeration of fossil shells. The Ystalyfera iron is produced from clay, iron-stone, and hematite, the fuel being anthracite coal, and the flux a light-colored limestone. These remarks are extracted from the recent Report on Cast-iron, ordered by the House of Commons to be printed, on July 30th, 1858. We may now pass on to describe the ordinary process of smelting. For the reduction of iron a blast-furnace is used of the form shown in Plate I.; but previous to smelting the ore it is sometimes necessary to calcine it, which is effected in a kiln of the form shown at Fig. 1. The kiln in which the ore is calcined is usually built in the

Fig. 1.

rear of the blast-furnace, the general form being that of the inverted frustrum of a cone; the diameter at top is usually about eight or nine feet, and the height fourteen or fifteen feet, with a bottom width of two feet. At the bottom of the kiln is an aperture through which the calcined ore may be withdrawn, and also a number of apertures for the admission of air; above the kiln runs a railroad, along which loaded waggons pass, and deliver the contents into the kiln. The general arrangements are best seen from the section above referred to.

When about to operate with a new kiln, the following course is

usually pursued: a fire is lighted on the floor, and as soon as full ignition is obtained other fuel is added, with alternate strata of ore, until the kiln is filled, care being taken to work the kiln so that these strata descend uniformly, being exposed to a higher temperature at the upper part of the kiln, where active combustion is maintained; the temperature diminishing as the ore passes towards the aperture, through which it is subsequently withdrawn. If the operation of calcining be continuous, which is most advantageous, the kiln requires to be filled regularly and continuously over its entire area, as irregularity or negligence in conducting the process of calcination will result in loss of economy. It is also necessary that the ore should be broken into pieces of uniform size. In some districts the ore is calcined in the open air, but this method of procedure is far from satisfactory. The perfect calcination results in the expulsion of its volatile constituents, such as water, carbonic acid, sulphur, and organic matter. By this process, also, any protoxide of iron which may exist in the ore is converted into peroxide.

Generally it is considered advisable to calcine ores of the same formation together; but if any particular sample should contain much sulphur, it is desirable to treat it by itself, in order to avoid contaminating cleaner samples. The expulsion of sulphur, when it exists in considerable quantity, is facilitated by the introduction of a jet of steam with atmospheric air, whereby the sulphur passes off in combination with hydrogen, the metal remaining oxidized.

The calcination being completed, the ores are ready to be subjected to the action of the blast-furnace. A section of one of these structures is shown on Plate I.; it consists of two truncated cones, joined at their widest extremities; the bottom of the furnace is called the hearth, and the lower part of the lower cone the boshes, and is constructed of fire-brick, or of a very refractory material called fire-stone. This part of the furnace is subjected to a very intense heat, and it is therefore necessary to construct it of such material as may be sufficiently durable. To prevent the occurrence of a sharp angle where the two cones are joined, either a curve or a narrow cylindrical belt is inserted, whereby the edges are rounded off, and a space formed which is called the belly. The upper cone or body of the furnace is formed by an interior lining of fire-bricks, which is again enveloped in a casing made up of

broken scoriæ or refractory sand, whereby the internal lining or shirt of the furnace is separated from the external coating of fire bricks, which is supported by a mass of masonry composed of stone and common stock-bricks. The opening at the top of the furnace is called the throat or tunnel-hole, and is surmounted by a chimney, in which there are openings through which the ore, fuel, and flux are supplied to the furnace. Air is supplied to the furnace by tuyeres or "tue irons," as they are sometimes called, consisting of nozzles, through which the blast is forced. In practice it is found advantageous to build the furnaces at the bottom of a declivity, so that the summits may be connected by a bridge at the neighboring high ground, in order to facilitate the supply of fuel, &c.; if, however, this cannot be done, they must be raised by an inclined plane, or by a hydraulic lift, or some other convenient means. The dimensions of these furnaces differ widely, according to the nature of the product desired and of the ores operated upon: the height varying from thirty-six to seventy feet, the most common height being about fifty feet; a furnace of this height producing on the average about sixty tons of cast-iron per week.

The blowing-machine ordinarily employed for supplying the

Fig. 2.

blast to the furnace is of the form shown Fig. 2. It consists of a large cast-iron cylinder, accurately bored, and provided with an air-tight piston; the cylinder is closed at both extremities by iron

covers, a stuffing-box being attached to the upper cover, through which the piston-rod passes; the whole forming a double-acting pump, driven by a beam-engine.

We will now describe the method of working practically the blast-furnace. Let us suppose that the furnace is newly erected. It is first requisite to light it. To prevent the masonry from being exposed to the injurious influence of sudden heat, the lighting is commenced by igniting a quantity of loose fuel in the arch forming the breast of the furnace. After some days, when it is sufficiently heated, fuel is thrown in through the throat, and allowed to rise as far as the middle of the boshes; when the drying is still further advanced, the whole internal cavity is gradually filled up with fuel, after which the blast is gradually and cautiously applied, being supsequently raised to its full pressure. When the fuel is sufficiently sunk, a small charge of the ore and flux is spread over it; after which, alternate layers of fuel, ore, and flux are added. The blowing-machine is almost invariably worked by steam-power and upon the average it may be calculated that one horse power is required in the blowing engine for every two and a half tons of metal produced per week. In one of the Welsh smelting-works it was found that furnaces producing sixty tons of cast-iron per week consume, on an average, three thousand six hundred cubic feet of air per minute, the power expended being one horse for every two and a tenth tons of metal per week. In the Continental furnaces, where charcoal is used, the blast-pressure frequently does not exceed half a pound per square inch. For coke, the pressure is from one and a half to three and a half pounds per square inch, the average being about two and a half pounds. The furnaces are sometimes worked with hot blast, and to heat the blast of a furnace producing sixty tons per week to the temperature of 600° Fahrenheit, about thirty-two tons of coals will be consumed weekly, being a little more than one-half the weight of the metal produced. But the blast is also sometimes heated by the combustion of gases drawn off from the upper part of the furnace, before they have become ignited by contact with the atmosphere. Various means of effecting this have been devised, but we shall not here occupy more space with the description of them. The cast-iron produced in the blast-furnace is usually run out into troughs formed in sand, from the sides of which smaller troughs branch out. The iron

formed in the main troughs is termed "sow," and that in the smaller branches "pig," which latter is supposed to be of better quality. The iron in this condition is ready to be used for castings, or to be converted into wrought-iron. Of the former process we shall treat hereafter: we will now proceed to consider the latter.

There are various methods employed for the refining of iron, but we shall here confine our attention to the English process. The transformation of cast into wrought-iron is effected by means of pit-coal or coke in two consecutive operations; in the first it is heated in a furnace, which is usually built on a mass of brickwork about nine feet square, the sides of the fireplace being formed of hollow cast-iron troughs, through which water is constantly circulating in order to prevent their fusion. The metal is fused in this furnace, and subjected to the action of the blast, whereby a considerable portion of its carbon is oxidized and removed, and also nearly the whole of its silicon. The metal, which is usually covered with blisters, is then run out into flat moulds. A section is shown at Plate II.

The further purification or puddling is conducted in a reverberatory furnace, when the remaining impurities are to a great extent removed by oxidation. The puddling of fine metal from the refinery, is thus conducted. The sole, or centre part of the furnace, is charged with broken metal, rich slag, and iron scales; the doors and sides of the furnace are now closed, and fuel thrown on the grate. When the metal begins to melt, the door is opened and the charge continually stirred until it arrives at a pasty state, when the fire is lowered. The metallic bath now appears to boil, from the evolution of carbonic oxide, which burns on its surface with a blue flame. The stirring of the mass is then continued until it becomes sandy, and subsequently of an uniform granular appearance. The iron is now said to work heavily, and a portion of the scoria runs off; after which the iron is formed into balls, heated in the hottest part of the furnace, and the slag expressed under a hammer or squeezer. The charge of a puddling-furnace is usually from three and a half to five tons. A section of one form of a reverberatory furnace is shown at Plate III.

We may here mention Mr. Bessemer's process for refining iron. This consists, firstly, in running the fluid-iron from the furnace

into a closed or nearly closed vessel, after which air is forced through it, thereby affording oxygen sufficient to cause combustion of the iron, and the oxidation of other impurities. A section of the vessel used is shown.—Fig. 3.

Fig. 3.

Mr. Clay has also proposed to refine iron by a process of granulation produced by dropping iron from the top of a lofty tower into a water-tank, in the same manner that lead shot is cast, and it is stated that by this method so large a surface is exposed to the oxidizing influence of the air that the metal is purified by the oxidation of its foreign ingredients.

It has also been proposed to oxidize the impurities by allowing the molten metal to fall upon a cone a few feet from the floor, whereby the crude iron should become finely divided, thereby exposing a considerable surface to the action of the atmosphere.

We have yet to speak of the formation of steel, but on this

subject we will be exceedingly brief. The wrought-iron intended to be converted into steel is usually drawn out into bars, which are subsequently packed in powdered charcoal in large cases, and there exposed in a suitable furnace to a bright-red heat, until the metal has taken up a sufficient portion of carbon to convert it into steel. Steel may, however, also be formed by subjecting wrought-iron at a high temperature to the action of a carburetted gas. A section of the furnace used for this process of cementation is shown at Fig. 4.

We will now turn our attention to the metallurgical operations

Fig. 4.

required for the manufacture of copper. The ores of copper are principally found in the primary and lower transition rocks. Red oxide of copper is an ore of a bright-red color, specimens of which may be found in Cornwall, Saxony, France, Siberia, Brazil, and the Lake-Superior district. Black oxide of copper occurs in granular masses of velvety-black color; it occurs in small quantities in Cornwall, and more abundantly in France, Siberia, and South Australia; but it is found in the largest quantities in the Lake-Superior district. Carbonate of copper is commonly found

in reniform, mammillated, or botryoidal masses. It is found in Siberia, South Australia, and Cornwall, and contains about fifty-five per cent. of metallic copper. Sulphuret of copper is the most abundant deposit of copper in the whole world, and of this many species occur; but the most common ore in England is the sulphuret of copper and iron, the extensive copper mines of Cornwall and Devon being principally wrought upon this ore. The first process of which we have to speak is the cleansing of the ores. The ore is first crushed and sifted, and subsequently washed or jigged: which consists in placing the ore in a sieve in a cistern of water, and jerking it up and down. By this means the portions of ore are momentarily suspended in the water, and are presently found to arrange themselves with the largest pieces at the bottom, and the smaller fragments above. The hand process of jigging is, however, applicable only to small pieces of ore; and when larger quantities are to be dealt with, machinery driven by steam or water power is substituted for the hand-sieve. The round buddle

Fig. 5.

is also used for cleansing copper ores. This apparatus, of which a section is shown at Fig. 5, consists of a conical bed, on the centre of which a stream of water continually pours, where the ore is also supplied, being uniformly distributed by means of brushes suspended from arms on a vertical spindle. The specific gravity of the ore on this apparatus determines its position, the richest mineral being deposited at the centre, the deposit diminishing in value towards the outer edge of the buddle, where a broad ring of tailings, or refuse matter, is taken out; the ores thus cleaned

are ready for the smelter. The smelting of copper is conducted in reverberatory furnaces, differing slightly in form, the treatment being complicated, the mineral undergoing ten operations. In the first, the ores are roasted or calcined in order to volatilize such substances as sulphur, zinc, arsenic, antimony, &c. The second process consists of fusing the calcined products with other minerals not previously calcined; this is called roasting for coarse metal. In the next operation, the remaining sulphur, which could not be driven off by heat alone, is expelled, it being alternately exposed to the action of an oxidating flame and that of a reducing flame. The fourth process is termed melting for white metal, in which the iron is eliminated as slag by combining it with silica. The fifth operation, melting for blue metal, is very similar to the fourth, the calcined coarse metal being fused with roasted ores rich in copper. The sixth process consists in remelting the slags, to cause the production of a matt, in which the copper in the various slags is brought together. The seventh process, roasting white metal for the production of superior white metal, has a twofold object: the charge being first oxidized to decompose the sulphuret of iron into oxide of iron and sulphurous acid, the latter being evolved, while the former combines with silica, and is carried off as a fusible slag. The whole mass is then melted. The eighth operation, roasting for regulus, is conducted with the following effects:—Oxidation first occurs, but as the fusion proceeds the oxide of copper reacts with the sulphuret: sulphurous acid is evolved, and metallic copper, or a sulphuret of copper, is produced; the products are three, all of which have to be reworked: a regulus containing twenty-one per cent. of copper, a slag containing about ten per cent., and bottoms, or alloys with other metals. The ninth operation comprises the roasting and fusing of regulus for crude metal; and the tenth process consists in the refining and toughening of the same. After fusion, the scoria is raked off the surface of the metal, and a few shovelfuls of powdered anthracite or wood-charcoal are thrown on the surface of the charge, after which it is stirred with a pole of green wood for about twenty minutes, after which it has attained the condition of fine metal. This brief account contains the substance of the ordinary process of copper smelting.

The most common ores of zinc are the carbonate, the sulphuret, and silicate. The ores are first roasted or calcined, and the zinc is

subsequently distilled from them in retorts, the forms of which vary in different districts.

The tin of commerce is obtained from the native oxide of that metal, some of the tin ores requiring, however, a careful cleansing previously to the smelting operation. By the first process the reduction is conducted in a reverberatory furnace, the fuel used being common pit-coal, the ores operated upon being mixed with a proper amount of powdered carbonaceous matter. By the second process, the oxide is reduced in a small blast-furnace, supplied with air by a blowing machine driven by steam power.

The ores of lead usually treated in this country principally consist of galena, or sulphuret of lead, which, however, before it comes into the hands of the smelter, has been deprived by a careful mechanical preparation of a large portion of the earthy and silicious ingredients with which it was originally associated.

The galena, or sulphuret of lead, is treated in a reverberatory furnace, where it is first subjected to a roasting process, which, by the oxidation of the constituent elements of the mineral, converts it into sulphate of lead and oxide of lead, which, re-acting on each other, cause the production of metallic lead, which frequently contains sufficient silver to render its extraction a matter of commercial importance. As, however, the process by which the silver is separated belongs rather to the metallurgy of silver than to that of lead, we shall not here occupy our space with an account of it.

From the foregoing descriptions we find that the reverberatory furnace admits of a greater range of chemical re-actions than the blast furnace will allow of, and it may be interesting here briefly to review the chemical operations occurring in the two furnaces.

In the ordinary blast furnace deoxidation of the metalliferous minerals alone takes place, and in the iron furnaces it occurs in the following manner.

The ore and fuel are, as before stated, thrown into the furnace in regular strata, and descend in the same order to the belly, or upper part of the boshes. The temperature of the upper part, or cone, is not very considerable, but in the neighborhood of the boshes more heat is evolved, and on the hearth it is developed in its fullest intensity. The air thrown into the hearth there meets with fuel in a high state of incandescence, and from the large excess of oxygen present, a vigorous combustion ensues. The

combustion produced by the blast usually extends as far as the middle of the boshes, but its activity is there much reduced, as the greater part of the oxygen has been converted into carbonic acid before the ascending current reaches that point. The carbonic acid then combines with carbon to form carbonic oxide, which subsequently exercises a powerful reducing influence on the oxide of iron.

In the reverberatory furnace an oxidating influence may be obtained by the introduction of atmospheric air to the sole, or laboratory of the furnace, or the metal may be deoxidated in a manner similar to the action of a blast furnace; or it may be merely fused, by adjusting the admission of air so that its oxygen is almost entirely removed before passing the fire-bridge.

## CHAPTER II.

### ON FORGING IRON.

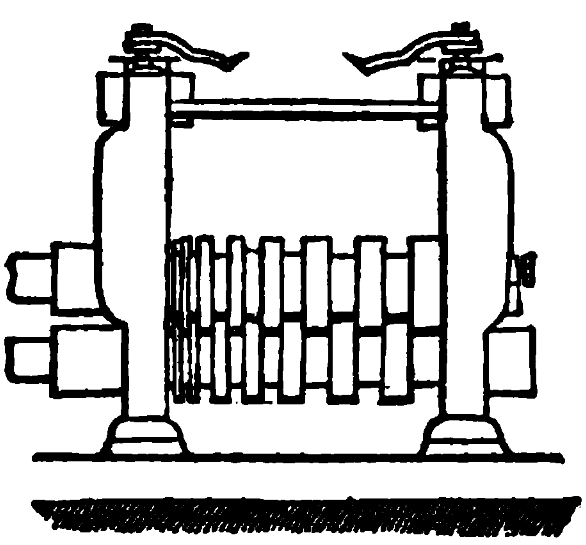
THE earliest process of forging which iron undergoes has for its purpose the forming of the blooms or balls of iron into bars or plates, in order that they may subsequently be applied by the mechanical engineer to the various purposes for which they are required. In this operation the blooms are frequently operated upon by hammers raised by a shaft furnished with cams, or projections, which act upon the tail of the hammer; but the most effective apparatus is the steam-hammer, of which various forms have from time to time been produced. We shall, however, here describe a fifty-cwt. steam-hammer on Nasmyth's plan.

An elevation of this steam-hammer, with a section of the foundation, is shown, Plate IV. The apparatus consists of a very strong cast-iron frame, supporting at the top a steam cylinder of the ordinary construction; within this cylinder is a piston, to which is attached a piston-rod, working steam-tight through the bottom cover of the cylinder; at the lower end of this piston-rod is a large mass of metal which constitutes the hammer-head; to the lower surface of this block the hammer-face is fixed by a dovetail joint, firmly wedged up. To the lower part of the steam cylinder the slide valve is attached, being surrounded by a jacket, as shown; it is worked by the action of the hammer-head upon a tappet, placed in front of the guides by which the hammer-head is retained in position during its fall, or by the hand-gear, shown. Beneath the hammer is an anvil, with a hard face dovetailed into it, and wedged up firm; the whole apparatus rests on foundations consisting of piles for the support of the anvil, and of cinders beaten down for the support of the hammer-frame. The action of the hammer is as follows: the steam being admitted beneath the piston, raises it, together with the hammer-head; when a sufficient elevation has been obtained, the steam is allowed to escape, and the

hammer-head falls upon the work to be wrought, the operation being repeated as often as may be desirable. The machine can be worked by those accustomed to its use with great accuracy, very delicate operations having been frequently performed, such as the corking of bottles, cracking of nuts without injuring the kernels, &c.

We may also include among the machinery used in forging iron, the rollers employed to reduce it to the form of bars; for this purpose, stout cylinders, with grooves turned upon them, are employed, the metal being passed through grooves gradually diminishing in size until the metal is reduced to the desired dimensions; the general form of this apparatus is shown in Fig. 6. For rolling plates true cylinders are required, and very great care must be employed

Fig. 6.

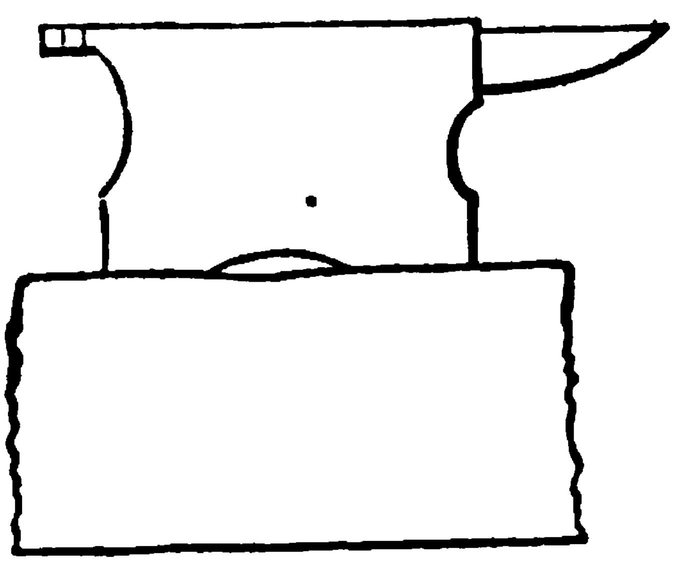


for the production of thin plates. We may now proceed to describe the smaller machinery of the forge; we must first, however, mention, that it is very important to select coals of a suitable nature as fuel for the forge; the best for the purpose is a strong, dense, durable coal, possessing a good body, dull and dirty in appearance. Bright, easily-broken coal is not good for this purpose, and such matters as tend to combine with the iron in the form of clinkers are very deleterious, sulphur being an element which should especially be avoided in forge-fuel. Tanfield coal, when unmixed with other varieties, is very convenient for the smith's work.

The first piece of apparatus of the smaller class which we have to describe is the forge-furnace, which is used when small portions of iron are being worked, larger masses being heated in a reverberatory furnace; these forges may be made eight or nine feet

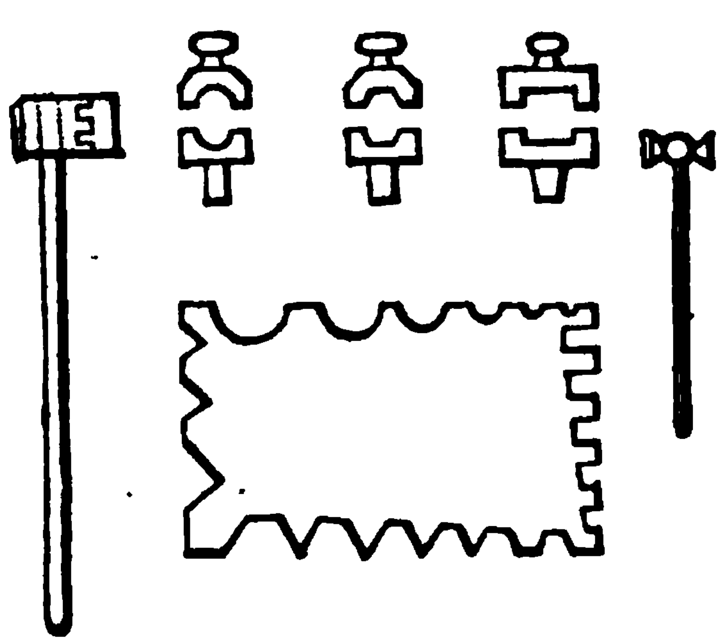
square, and consist of a mass of brick-work as a foundation to support the fire; at the back of the fire is a tue-iron, through which a blast is supplied. This blast is frequently produced by a revolving fan; the whole is surmounted by a hood and chimney, which serve to carry off the smoke and heated air. The iron is worked upon a stout mass of iron, called an anvil (shown Fig. 7). It is rested

Fig. 7.



on a large block of wood, to raise it to a convenient height, and the metal is beaten by means of sledge-hammers and hand-hammers, swages or dies being used when requisite, to produce any particular form. The lower swage is fitted to an aperture in the anvil, the iron to be wrought placed upon it, and the upper swage laid on the iron, and struck with the hammer. The upper swage is held by means of a light hazel rod, which prevents the shock

Fig. 8.



of the hammer from producing any strain upon the hand of the operator. For ordinary forgings, two men are employed: the smith, who is responsible for the work, and receives a high salary, and the hammer-man, or striker, whose duty it is to wield the

sledge-hammer, and work the bellows, when such are used for the maintenance of the blast. Some forms of swages, and also a combined bottom swage, or swage-block, are shown at Fig. 8, as also a sledge and a hand-hammer.

For welding iron a flux is required, in order to prevent the oxidation of the surfaces to be joined. For this purpose fine white sand and common salt may be used. The iron is first heated, dipped in the flux, and the heating continued, until the metal has attained a white heat. The flux is then fused over the surface, and has dissolved any oxide of iron which may have formed; the two surfaces to be joined are laid together and struck continuously, working towards the edges, in order to expel the flux and insure a perfect union of the metal. Cast-steel and wrought-iron scarcely admit of being welded together with facility; but shear-steel may thus be joined to wrought-iron; in which case, however, the steel is not raised to nearly so high a temperature as the iron.

For heavy forgings a crane is also required, but the form of this is too well known to require any special description. In large forgings each particular piece of metal requires different treatment, according to the use for which it is destined. Thus the heavy screw shaft, which is subject to torsion only, will require a different arrangement to that employed when a crank or cross-head is formed. The most ancient method of forging shafts consisted in piling together a certain number of slabs of iron, which were subsequently heated, welded, and hammered into the cylindrical form required. When, however, it became necessary to make larger shafts, this method was improved upon: a pile of slabs being taken as before, of which only a portion was drawn out to the circular form, a large mass being left at one extremity, on which to weld more slabs when required: after which the metal could be drawn out a little longer, the operations being continued as long as was needful. This method is still employed at many works in England, Scotland, and America, with considerable success, but it requires the utmost care, both with regard to workmanship and materials. A far superior plan consists in building up the shafts with a sufficient number of square bars; for if, in the slab method, any oxide of iron or dirt should intrude itself between the joints, the seams will run across the shaft; whereas in the bar method they will be longitudinal. It is, however, very important to avoid

attempting to weld too great a faggot of square bars at once, as in that case it frequently happens that at the centre the bars are not welded at all. A few bars should therefore first be welded together, and when soundly joined, other layers of bars may be packed around this central core: the process being continued until the required size is attained, which can thus be effected with perfect success. Another method consists in first making a round core or heart, and packing around this bars of a V form; this method is adopted frequently for forging railway axles, and it was also employed in the manufacture of the monster gun at the Mersey Ironworks. From a paper by Mr. Clay, we find that the method employed in forging this gun was as follows. The gun was built up in seven distinct layers or slabs, the forging occupying seven weeks, and it was found that the metal, after being worked, was improved in strength rather than deteriorated, by the long exposure to great heat. The chief points to be considered by the designer of the gun were, to obtain sound weldings, to place the iron with its fibres in the proper direction for resisting the most severe strain to which it could be exposed, and to take care that while one part of the forging was being worked, other portions were not wasted under the action of the furnace by burning or crystallization.

The first operation was to prepare a core of suitable dimensions and nearly the whole length of the gun. This was done by taking a number of rolled bars about six feet in length, and welding them together, and then drawing them out until the proper length was obtained: a series of V-shaped bars were now packed round the core, heated in a reverberatory furnace, and forged under a large hammer. Another series of bars was next packed on, the mass again heated, and worked perfectly sound. Another longitudinal series of bars was yet required over the whole length of the forging, after which the work was about fifteen feet in length and thirty-two inches in diameter, but requiring to be augmented to forty-four inches at the breech, tapering down to twenty-seven at the muzzle. This was accomplished by two layers of iron, placed in such a manner as to resemble hoops laid at right angles to the axis of the mass, and after two more heatings and careful weldings, the forging of the work was complete. After each important addition, a securing heat was given to prevent flaws.

A great deal has been written at various times on the crystal-

lization of wrought-iron under the action of heat long continued, more especially when the metal is allowed to cool slowly, and also when the metal is subjected to the action of blows frequently repeated; some experiments have, however, tended to disprove the theory of crystallization by heat; but we have seen bars of iron, originally of a tough or fibrous character, snap with a force far below the calculated resistance of the material, the fracture exhibiting a beautiful crystalline texture.

The forms of iron ordinarily obtainable in commerce are as follows: square, round, elliptical, rectangular, semicircular, segmental, channel, T, H, and L iron bars, also plate and sheet iron; the thinnest being that employed for the manufacture of tin plates.

It is unnecessary here to dilate upon the forging of copper, it being only necessary to observe that it is worked at a low temperature, and that when it is wrought cold it is necessary occasionally to anneal it by heating.

Besides the tools already mentioned, various tongs, and also various special forms, are frequently required to execute hollow or other work, which cannot conveniently be wrought upon the anvil; these are called stakes. Among the swages occur some having at their extremities a conical or cup-shaped recess, intended to complete the heads of rivets; these are termed snaps, and are sometimes worked by machines termed rivetting machines, being attached to piston rods, acted on by pistons working in cylinders of large diameter but with a very short stroke.

## CHAPTER III.

### ON MOULDING AND CASTING.

FOR many purposes it is found convenient to produce articles from molten metal, by a process termed casting, which consists in pouring the metal in a fluid state into a cavity which corresponds to the form of the article to be produced. Several methods of producing these cavities are in use, but we shall here confine our attention to the manipulations included under the head of green or baked sand-mouldings, loam-moulding, and moulding for chilled castings. We will first speak of green sand-mouldings.

The first operation to be performed, when it is proposed to make a green sand-casting, consists in making a model or pattern of the article to be produced. This may be made of wood; it must be in form similar to the required object, but tapered so that it may admit of being readily removed from the sand in which the casting is to be made; and it must also be larger than the finished article, in order to allow for contraction in cooling, and also for the removal of material in producing finished surfaces. The contraction is, for iron, about a tenth of an inch to the foot, and for brass one-eighth of an inch may be allowed. All apertures in the intended casting are produced by pieces called cores, fixed in the mould; these are retained in position by being made longer than the apertures to be produced, the excess of length being inserted into recesses formed in the sides of the mould. These recesses or hollows are produced by protrusions upon the pattern or model, such protrusions being called core prints.

Cores are also used, under some circumstances, for the production of undercut recesses.

We may perhaps best illustrate the manner in which the casting is produced, by taking an example, and describing the process required for the completion of such example. Let us suppose that the poppet-head of a lathe, which is of the form shown, Fig. 9,

having an aperture running through the whole length of the upper cylindrical part, is required. The pattern will be of the form shown at Fig. 10, being furnished with core prints, as shown at

Fig. 9.

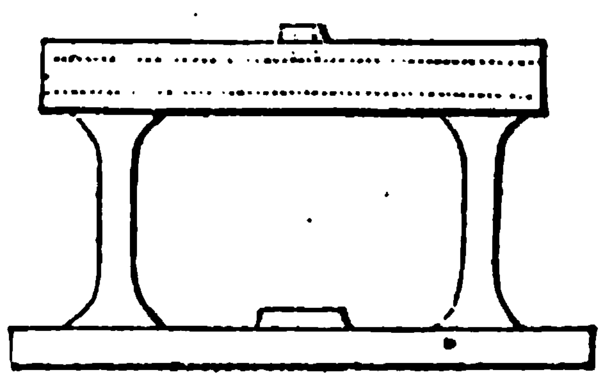
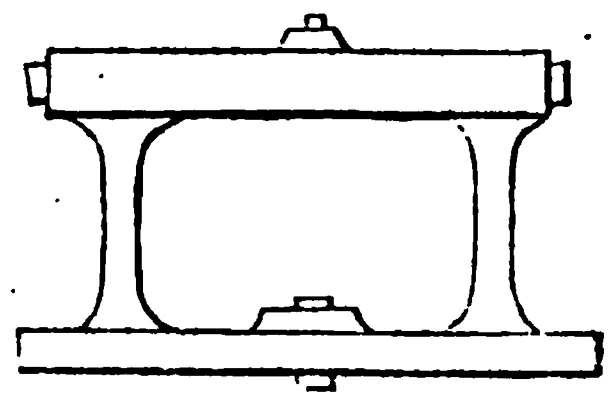


Fig. 10.



each end of the cylindrical part. The process of moulding is conducted in the following manner. Two boxes, having neither top nor bottom, but capable of being fitted together by means of pegs fixed in lugs on one frame, which fit into apertures in lugs on the other frame, together called a flask, are used to contain the sand of which the mould is to be made. One flask is taken and placed with the lugs downwards upon a smooth slab, and filled with moulding sand, which is firmly rammed down. The flask may then be inverted, the sand being retained in the frame by its cohesion and adhesion to the sides of the flask; but when the latter is large, it is, for greater security, furnished with transverse bars. After the frame has been inverted, the upper surface presents a smooth and level appearance, and in the centre of this a hollow is scooped resembling the form of the article to be cast. In this the pattern is bedded in a horizontal position, being sunk in the sand to as nearly as possible half its thickness; powdered charcoal or coal-dust is now sprinkled over the whole surface, and the upper part of the flask adjusted in position; it is then filled up with sand, which is firmly rammed down around the pattern. The two parts of the flask can now be separated, the adhesion of the sand being procured by the layer of charcoal dust mentioned above. The impression formed in the sand of the upper flask is smoothed and repaired, where necessary, by trowels of a suitable form. The sand placed in the first frame is now broken up, the frame which served as the top of the flask placed with the cavity uppermost, the pattern placed in the cavity, the empty frame fitted on, and the whole filled up as before. The flask is then again taken in pieces both cavities repaired where necessary, and openings made from

the cavity in the upper frame, through to the surface of the sand. These are called gates, or gits, and serve, some of them, for the admission of the molten metal, and others afford egress to the air in the cavity and the gases generated by contact of the hot metal with the sand. The core, previously made, of tough loam with chopped straw or other filamentary material, and dried, is now inserted in the core prints; the flask is then put together, the two parts being secured by pins or wedges passed through apertures in the extremities of the pegs fixed to the lugs of the lower frame. The metal may then be cast. When the casting is sufficiently cool the mould is broken up, the superfluous metal knocked of; and when the casting is quite cool, the false seams are cut off, the core cleaned out, and the hard sandy coating rubbed smooth with a piece of oven-coke.

We may now mention a few particulars to be observed in the general preparation of moulds. Ample space for egress of gases must be allowed, wherefore it is desirable to pierce the sand to within a small distance of the cavity, by means of a stiff wire; also to form a sufficient number of gits. The sand should be of open texture, but of a binding character, otherwise the casting will be apt to scab,—that is to say, there will be a liability in the sand to scale off the surface of the mould, and rest on the surface of the casting. If sufficient egress be not allowed for the air, blow-holes will occur within a short distance of the surface of the casting, thereby materially reducing its strength. It is usual to tap the pattern with a hammer in order to loosen it, previous to withdrawing it from the mould, thus preventing the risk of damage to the mould, and for this purpose wires are sometimes screwed into the pattern, which protrude through the surface of the sand and the upper part of the flask. Very heavy patterns may be removed from the sand by the united efforts of several men, each lifting the pattern with one hand while with the other he taps it with a light hand-hammer.

If the sand be used too damp, hard places will be formed in the casting, thereby adding materially to the difficulty of subsequently working the metal.

Moulding in baked sand is conducted in a manner similar to the above; but the sand is used in a more moist condition, the mould being subsequently dried in a suitable furnace. Moulding in loam

is conducted in a manner quite different from the method employed for moulding in green sand—no pattern being used; we may take as an example of this class of moulding the formation of a hemispherical melting-pot. A cast-iron ring is laid down on the foundry floor, and upon this a brick dome roughly approaching the internal form, is erected, an aperture, however, being left at the upper part. A quantity of loam, formed of clay, water, sand, and cow-hair, after having been reduced to a paste and thoroughly kneaded in a pug-tub, is laid on the brick dome with trowels and smoothed with the hand; a fire is then lighted within the dome by means of apertures left on the cast-iron ring, a stratum of fine loam laid over the first layer, and formed to the exact contour of the interior of the vessel by means of a scraper of suitable form, attached to a vertical spindle passing through the centre of the dome, and supported in bearings at the top and bottom, so that the scraper can be caused to revolve. The required form having been obtained, the scraper is removed, and the mould allowed to dry; after which it is thickly painted over with a mixture of charcoal, clay, and water, applied with a brush; another layer of fine loam is then applied equal to the thickness of the required article, and to it is imparted the exact form of the exterior of the vessel, also by means of a scraper. The whole is then again dried, the spindle being removed, and the aperture in the top of the dome filled up. The mould is again painted. Another ring is now laid down around the former and adjusted to it by steady-pins; the mould is covered with a layer of fine loam and then with a thicker stratum of coarse loam, and surrounded by brick-work. We shall now have an interior dome and an exterior shell, containing between them a quantity of loam corresponding to the thickness of metal in the required vessel. The outer shell is removed by lifting the outer ring by means of a crane, the painting of charcoal paste preventing its adhesion to the substratum. It is repaired with trowels, the intermediate thickness of loam is then broken off, and the surface of the interior dome smoothed and repaired where necessary. Gits are prepared in the outer shell, which is replaced, and the metal cast. As soon as the casting has become sufficiently cool the brick-work of the interior dome is loosened, in order to allow of the free contraction of the casting.

All moulds having the form of solids of revolution can be thus

produced by scrapers, but other forms must be obtained by aid of templates, or the workman must depend upon the correctness of his own eye.

We have yet to mention chilled casting. This consists of substituting metal surfaces for sand, wherever the casting is required to be peculiarly hard, this effect being produced by the rapidity with which the heat is conducted away by the metallic mould.

For large castings the metal should be melted in reverberatory furnaces; for smaller ones a small kind of blast furnace called a cupola is used. This consists of a low brick-work foundation upon which a sheet-iron cylinder is placed, which is lined with refractory sand, and surmounted by a low chimney or conical hood; holes are formed in the side of the cylinder to admit nozzles, through which the blast may be supplied, and also to allow the molten metal to be drawn off. The fuel and metal are supplied in alternate layers, and the metal as it melts accumulates in the bottom of the furnace. The charges are in the proportion of twenty-five coke to a hundred of iron; and the latter begins to melt about twenty minutes after its introduction into the furnace. For large and heavy castings the moulds are sunk in the floor of the foundry, and the metal run into them from the cupola, along channels in the sand of the foundry floor. For small castings the molten metal is carried in ladles lined with refractory clay; and for larger castings, large ladles or shanks, moved about by a crane, are used. Every casting requires more metal than is requisite to fill the mould, the excess going to form false seams, &c., and besides this there is an actual loss of six per cent. of the metal; so that after deducting all losses, each hundred-weight of coke melts about three hundred-weight of pig-iron. The following are the dimensions of an average-sized cupola, capable of melting five tons of metal at one time: height, nine feet; external diameter five feet; internal diameter, three feet six; height of first tuyere hole, two feet six inches; distance between tuyeres, fifteen inches; diameter of nozzles, from three to five inches; speed of fan, seven hundred revolutions per minute, to maintain which a power of three horses will be required.

## CHAPTER IV.

### ON CUTTING TOOLS.

In the present chapter we purpose to describe the various forms of tools used for cutting and abrading metal. The first of these to which we shall direct our attention are files. The general form of these is too well known to require any detailed description at our hand. The teeth are produced by making a series of cuts with a chisel along the whole length of the file, and dividing the ridges thus raised into teeth by other cuts crossing them at an angle, after which the tool is hardened. In cutting square and flat files it is usual to leave one side smooth to rest against the work without injury to it, thus forming a safe edge. When the file is only cut in one direction it is termed a float. A rasp has various isolated points raised upon its surface. The variety of files is almost endless, depending as they do upon the nature of the work for which they are required; but only a few of these are necessary for the execution of those branches of mechanical manipulation of which we treat. These are divided into three classes, viz.: taper, hand, and parallel. Those of the first description taper to a point, the second are formed with sides nearly parallel, and the third quite parallel, so as to be of the same thickness throughout. Files are also distinguished according to the fineness of their teeth, as follows: rough, bastard, second-cut, smooth, and dead-smooth. Taper files vary in length from four to twenty-four inches, are rectangular in section, and rounded in width and thickness. Hand files are more parallel in width, and less taper in thickness than the foregoing, and are commonly used for flat surfaces when greater accuracy is required than can be obtained with ordinary taper files. Cotter files vary from six to twenty-three inches in length; they are employed for filing grooves for cotters, keys, or wedges, used for fixing wheels upon their shafts. They are narrower than hand files,

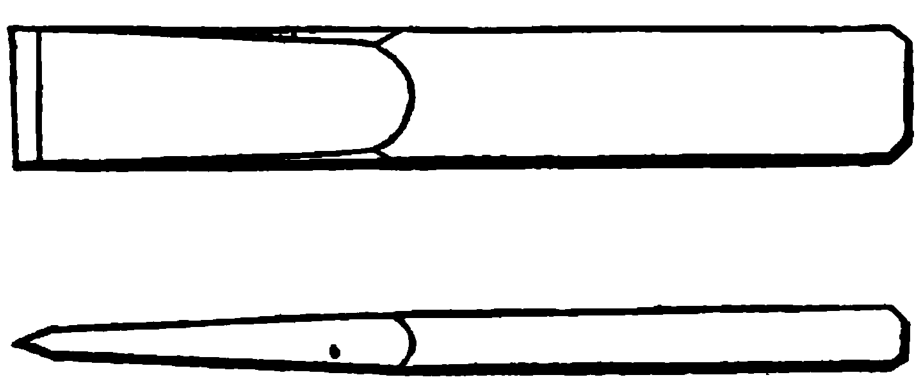
and nearly flat on their sides and edges. Pillar files are similar to hand files, but much smaller, varying from three to ten inches in length; they are usually formed with one safe edge. Half-round files have a segmental section, varying from one quarter to one twelfth of a circle, one side of the file being convex the other flat; their length varies from two to eighteen inches. Crossing files, or double half-round, are circular on both sides. Triangular, or three-square files, are made from two to sixteen inches in length; they are used for internal angles, for clearing out square corners, and for sharpening saws. Round files are usually taper, from two to eighteen inches in length, being used to enlarge round holes. Square files vary from two to eighteen inches in length, and are generally taper, having one or more safe edges; they are principally used for small apertures.

We will now proceed to speak generally of the angles of cutting tools. Scrapers are usually formed with edges contained between facets, making together an angle of from 55° to 60°. As a general rule, the softer the material the more acute may the angle of the cutting edge be: and the angles vary, for brass, copper, iron, and steel, from 65° to 90°; those for iron varying between 85° and 90°. Great care must be taken in order to obtain the angles of the cutting edges well defined, otherwise their action will not be satisfactory.

We will now speak in detail of the various cutting tools with which the mechanical engineer must be provided; commencing with hand tools, and subsequently describing machine tools.

Fig. 11 exhibits two views of a cold-metal chisel of the form

Fig. 11.



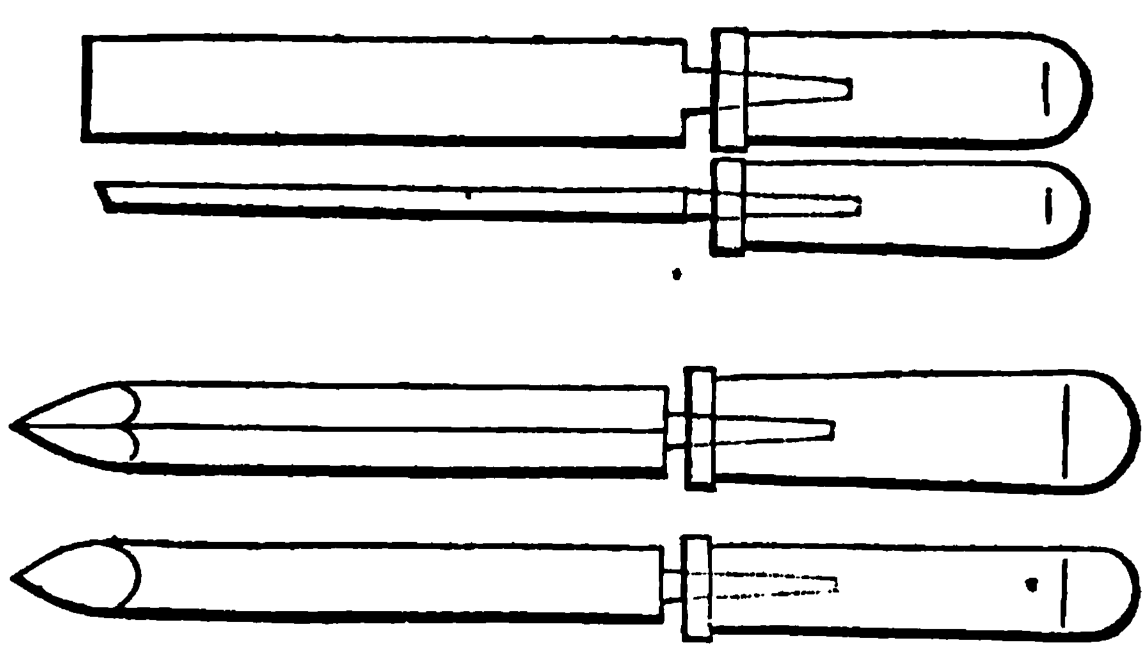
most commonly used, having a wide edge. These are ground on both sides to an angle from 70° to 80°,—for some particular pur poses being even more obtuse. They are tempered down to a deep straw color, and when in use are held in the left hand upon the

work undergoing manipulation, and driven by blows struck with a hand hammer held in the right hand. A similar form of chisel, attached to a hazel rod and driven by blows of a sledge hammer, is employed by smiths for cutting hot iron; but it is shorter and of a stouter make, being furnished with a wider edge. There is another form of chisel occasionally used for cold metal, having a semicircular edge; this is ground on the flat side and is used for clearing out grooves of a circular or elliptical section.

Small hand punches are also frequently employed for piercing thin metal, being formed of round steel, tapered off and ground flat at the end. Centre punches, which are used for marking work where holes are to be drilled, produce a conical or counter-sunk recess, and are themselves formed of round steel, tapered and ground to a conical point, with an angle of about 80°.

Scrapers are usually made in one of two forms: an old parallel file is taken, the teeth are ground off, and the end is ground smooth, so as to produce an angular scraping surface; or an old three-square file is used, the teeth being ground off, and the faces near the extremity ground convex, so as to terminate in a point, thereby forming three scraping-edges, each having an angle of 60°. The two forms of scrapers are shown in the accompanying Fig. 12.

Fig. 12.

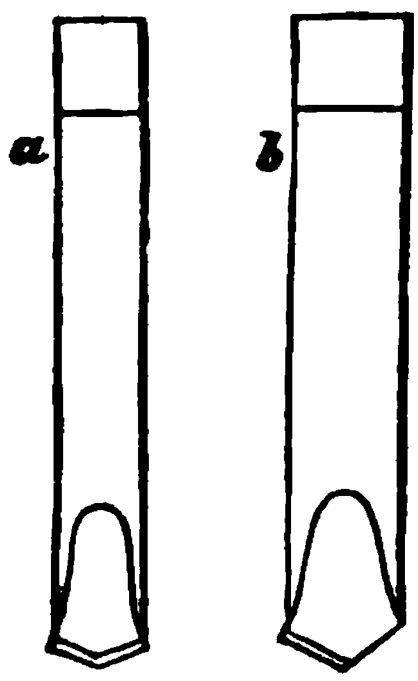


We may here mention, among fitters' tools, the metal saw. It is a kind of frame saw, consisting of a thin, narrow blade, furnished with teeth, tightly stretched in an iron frame. Saws of this description require frequent sharpening.

Small drills worked by hand are in constant requisition. They are of two sorts: those that are worked with an alternate recipro-

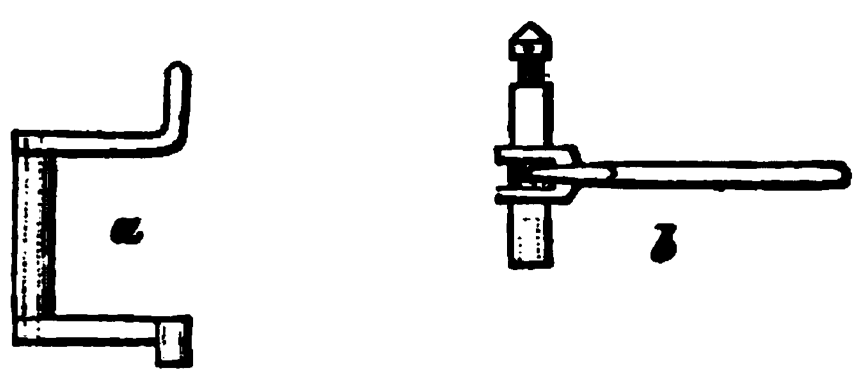
catory motion, ground on both sides, so as to scrape equally well in both directions, shown at *a* in Fig. 13; and those worked with a continuous circular motion, ground on one side only, shown at *b*, so as to cut in one direction; drills of the former description are usually fixed in a shaft, the tail-end of which is conical, and rests in a counter-sink formed in a breast-plate worn by the operator, through which the requisite pressure is imparted. Upon the shaft is fixed a sheave or pulley, around which the string of a steel bow passes; by imparting an alternate rectilinear motion to the bow, the wheel, shaft, and drill are caused to revolve alternately in opposite directions, thereby penetrating the material which is being operated upon.

Fig. 13.




The second class of drill is usually employed either in a brace, consisting of a crank, as shown at *a* Fig. 14; but when the hole is

Fig. 14.




to be drilled in a position which does not allow sufficient room for the brace, another kind of stock, called a ratchet brace, *b*, is made use of. This consists of a stout shaft, furnished at one end with a socket to receive the tang, or tail-end of the drill; and at the other with a screw, on the head of which is a hard conical point, and by means of which the requisite pressure is imparted to the drill; in the centre of the shaft is a ratchet-wheel, firmly fixed, and embraced by the forked end of an arm or lever, furnished with a pall, acted upon by a spring, which causes it to fall into the teeth of the ratchet-wheel; thus, when the arm is moved in the direction in which the drill is made to cut, the pall catches in the teeth of the ratchet-wheel, and drives the wheel forward, but on reversing the motion, the pall slides over the teeth, leaving the drill stationary.

A great variety of minor drill stocks have been devised, but

they are calculated rather to entertain the amateur than to render efficient service to the practical engineer; we shall, therefore, not encumber our space with a description of them.

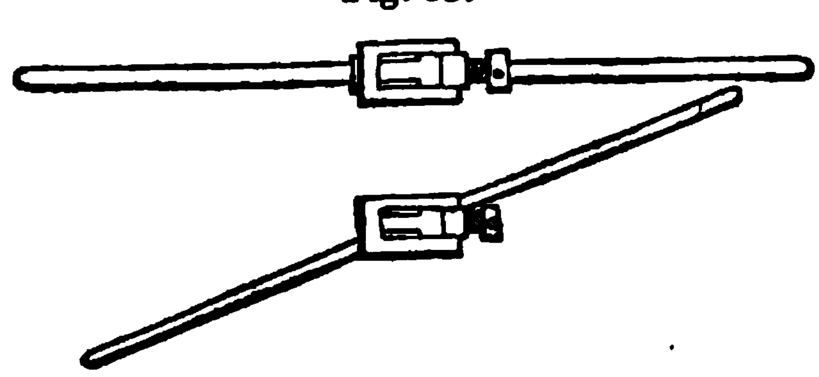
There are a class of scraping tools, known as broaches, or rhymers, employed for cleaning out circular holes; they consist of taper, triangular, square, hexagonal, or octagonal tools, of which the thickness is inconsiderable, when compared with the length.

Square holes are cleared out by means of steel drifts, consisting of taper steel bars, in which notches are filed at regular intervals, in order to give rise to cutting edges. A drift is forced through the aperture to be cleared by striking it with a hammer, and as these tools are made very hard, breakage frequently occurs.

We must now proceed to describe the methods by means of which screws are produced by manual labor. For the smallest screws a plate of dies, called a screw-plate, is employed; it consists of a plate of steel, in which threads have been cut, which are at certain parts filed away, in order that cutting edges may be formed, and also to afford a means of egress to the metal removed from the screw which is being cut. By means of this apparatus, the threads on a screw are partly cut, and partly squeezed up, being, therefore, not so perfect as those produced by the action of point tools, which will presently be described.

For the production of larger screws, such as the threads of bolts, dies made n two or more parts are used, the cutting edges appearing on the edges of the dies. These dies are used by means of stocks of the form shown, Fig. 15. In the centre of the stock is a

Fig. 15.



rectangular opening containing V-shaped ridges, which, fitting grooves in the dies, retain them in the stock. At one end of the rectangular opening, the ridges are cut away, in order to allow of the introduction of dies as required, which dies are adjusted by means of a set screw, in some cases formed on the end of one handle, of which construction we do not, however, approve, deem-

ing it preferable to have the handles firmly fixed, the dies being set up by separate screws.

Having concluded our remarks upon the means used for producing small solid screws without employing machinery, it is necessary to give an account of the method employed in making small hollow screws, or nuts. These are produced, first by drilling, and then by cutting threads by means of a hard steel screw, which we will now proceed to describe. Upon a piece of the best round steel, accurately turned, a screw is cut with great care, so as to be truly formed throughout; a portion of this thread is then removed by filing three or four grooves along the sides of the top, cutting edges being thereby formed, and a means of egress afforded the particles of metal cut away; the thread is also reduced towards the point of the top, thereby imparting to it a taper form, in order that it may gradually cut the thread, so that it may not overstrain either the tool or the material being wrought. Usually, for tapping a nut, two taper taps, and one plug, or parallel tap are used, being formed with a square head, which fits a rectangular opening in the centre of a stock, or tap-wrench, which is handed round in the same manner as a die-stock. Oil is used for lubricating these tools, in order to prevent their becoming heated.

A pair of shears for shearing metals is also used; they are precisely similar in their action to ordinary scissors, their edges being ground to an angle of about 85°. The blades are very short, and broad in proportion to the length of the shears. The ends of the handles are curved round, so as to meet and prevent the shears from closing too far.

There are other tools used by fitters, but as they are not, properly speaking, cutting tools, we shall defer the description of them to the chapter wherein we propose to treat of the manipulations included under the general head of fitting.

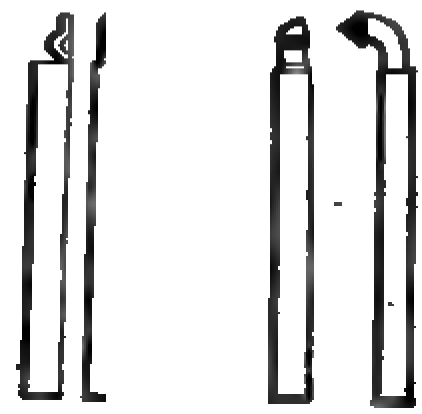
We will now proceed to describe the forms of the various tools used for operating upon metal by means of machinery. The machines themselves will be described in the following chapter.

The first tool of which we shall speak is known as the point tool; it is forged from square steel, as in fact are most of the machine tools. Two views are shown of it in the accompanying Fig. 16. This tool produces a surface consisting of very narrow grooves, the metal being generally removed by the action of the point and one

side of the cutting edge; it is used in the lathe, in the shaping machine, and in the planing machine.

Another tool has been derived from that which we have just described, which is most frequently used in the lathe, for taking large cuts, whereby the greater bulk of the superfluous metal is removed. This tool may be said to consist of one side of the point tool, the whole of its cutting edge being inclined to the axis of the work.

Fig. 16. Fig. 17. Fig. 18.



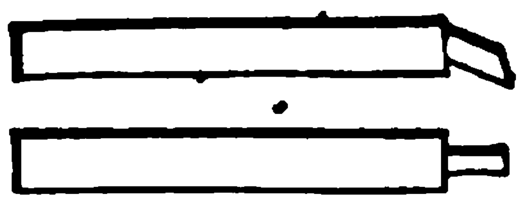
The next tool which we have to mention is the spring tool; it is formed with a spring or bend, as shown in Fig. 17, which enables it to yield to any hard particles which may occur in the metal being wrought, instead of tearing them out after the manner of the point tool. The spring tool is also much broader, somewhat rounded on the end, in order to prevent the danger of its corners from cutting too deep into the work. Hence this tool produces fewer ridges than the point tool, and such as do occur are more gradual in their ascent; the point tool is, however, capable of executing the work more accurately.

We may next speak of the side tool used for boring small cylinders, and also for cutting internal screws. A plan of this tool is shown in Fig. 18; when intended for boring, it is usually formed with a cylindrical part drawn out behind the cutting edge, in order to allow it to pass freely to the bottom of the cavity. When the tool is intended for cutting internal screws, the cutting edge should be made to protrude farther from the central axis than when the tool is employed for boring purposes.

Fig. 19 represents a parting-tool. It is used for cutting through or dividing work, and is made widest at the cutting edge, in order that the metal behind may not come in contact with the sides of

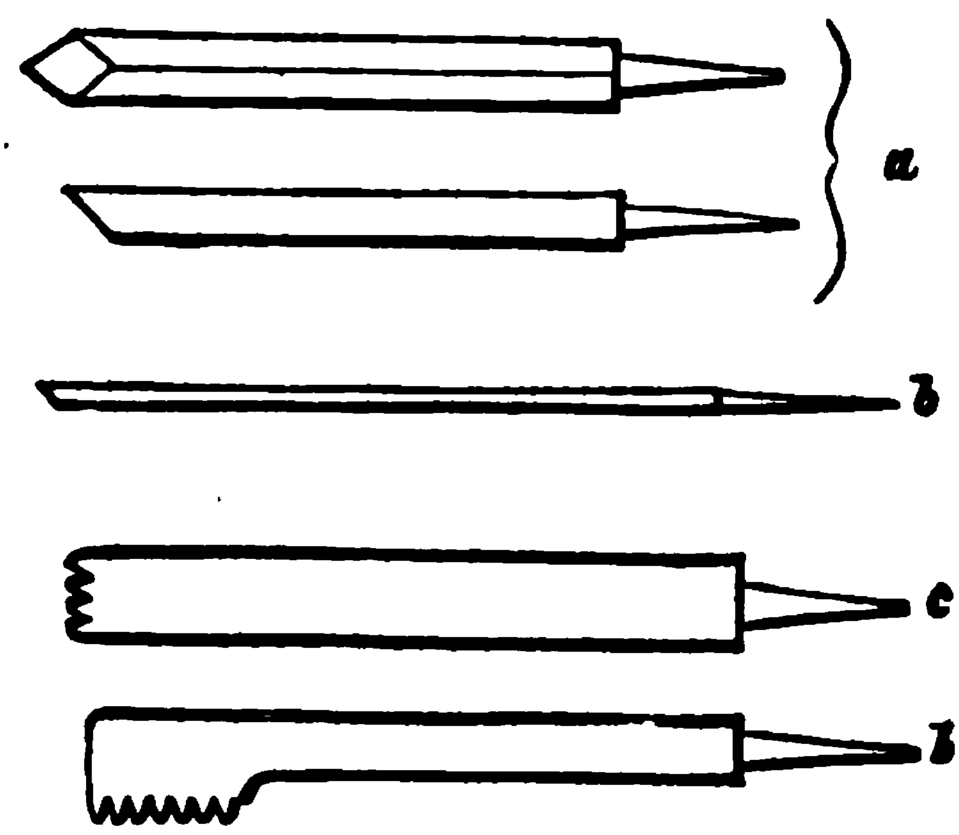
the cut. A tool very similar in form to this is used for cutting the threads of screws, its form being square, V, or otherwise according to the form of the thread required to be cut.

Fig. 19.



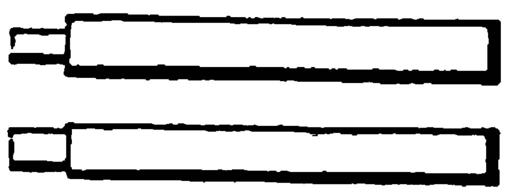
A number of hand tools shown in Fig. 20, are used with the lathe: *a* being termed a graver, *b* a flat tool capable of springing slightly, *c* a screw tool, *d* an internal-screw tool. Following the points of these screw tools, are threads which determine the pitch of the screw being cut.

Fig. 20.




We have yet to notice the slotting tool, which is used in the vertical-motion slotting machine; it is of the form shown, Fig. 21, and is chiefly used for slotting out wheels to receive the keys or wedges by which they are fixed to their shafts.

Fig. 21.



The machine tools already mentioned, are used with the turning lathe, planing machine, and slotting machine; but there are also

many forms derived from these used, to effect special purposes, which, however, are so similar in principle that it is unnecessary here to dilate upon them.

There are numerous small tools or cutters used in the turning lathe and drilling machine, principally for boring purposes: some of these are shown at Fig. 22. The remaining sketches in this

Fig. 22.

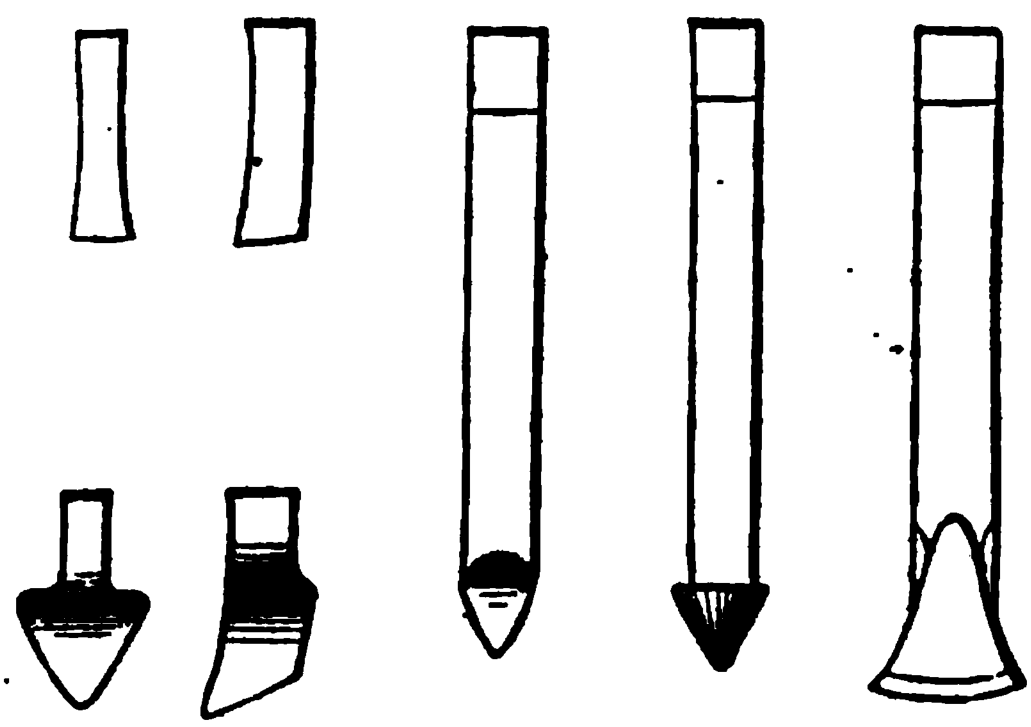


figure show various forms of drills used in the lathe and drilling machine.

Face and edge cutters of various forms are employed for grooving and trimming work; they are made by raising a number of ridges or cutting edges on the surface or periphery, as the case may be, of discs. Punches, shearing edges, taps, &c. used in machines, are similar in their general form to the same tools used by hand, but stronger, and the taps used for making screw tools are called hobs.

## CHAPTER V.

### ON WORKSHOP MACHINERY.

In the present chapter, we propose to describe and illustrate samples of the machinery generally required in the factory of the mechanical engineer. It would appear most reasonable first to describe the steam-engine, by which the workshop machinery is driven, but we shall not do so in this place, as the various forms of steam machinery are fully described in a subsequent part of this work. We may also here observe, that as the forge and steam-hammer have been already described, we shall not here refer to them.

The first machine to which we shall turn our attention, is the lathe, which is perhaps the most useful implement with which the mechanical engineer is provided. Plate V. represents a double-geared lathe, driven by steam-power; it has eighteen-inch centres; the bottom piece is the bed of the lathe, the surface of which is very accurately formed, by means to be hereafter described; upon this bed at one extremity is mounted a heavy head stock, which carries the gearing by which the lathe is driven; this gearing consists of two mandrils, one of which carries diminishing riggers, and two toothed wheels; the other shaft carries also two toothed wheels, gearing with the former. When greater variations of speed are required than can be attained by the speed riggers alone, these are loosened from the shaft by slacking a nut, which previously held them tight, up to the front spur wheel on the main shaft of the head stock, and the lathe is driven through the intervention of the spur gearing on the other shaft. The main shaft is called the mandril, and is in the centre of the lathe. At its extremity is a pinion, which gears into wheels by means of which a long screw is driven; this screw runs the entire length of the lathe bed, and serves to propel at an uniform speed the slide rest

which we now proceed to describe. It consists of a stout foundation-piece, which fits accurately the top of the lathe bed, admitting of a sliding motion upon it. Upon this foundation-piece is placed another slide as shown, worked by a screw attached to the foundation-piece: its motion is at right angles to the lathe bed. Above this is a smaller slide, also worked by a screw, as shown; it moves parallel to the lathe bed, but admits of adjustment to any required angle. On the top of this slide the cutting tools are held by means of short bars pressed down upon them by nuts working on studs, as shown. The entire slide rest admits of being moved along the bed of the lathe, by a handle acting upon a pinion gearing in a rack attached to the lathe bed. In order to move the slide in this manner, it is necessary to throw it out of gear with the long screw, or leading screw, as it is termed, which is effected by opening the gearing nut, made in two parts, in order that it may admit of this movement. At the farther end of the lathe bed, is shown another head stock called the poppet head; this, like the front head stock, is furnished with a mandril, at exactly the same height from the lathe bed. The mandril in this head is hollow, and admits of longitudinal motion, by means of an internal screw, worked by the hand wheel shown at the back of the head. The poppet head is also capable of sliding on the lathe bed, being secured in any required position by means of a clamp drawn up tight against the lower side of the top of the lathe bed, by means of the bolt and nut shown. Each of the mandrils is fitted with a conical centre, whereby work to be operated upon is supported. On the mandril of the front head is shown a disc or chuck, whereby the work in the machine is caused to revolve with the mandril. Some chucks are simple perforated discs, perforations allowing bolts to be passed through, by means of which the work is secured. Other chucks are made with L-shaped pieces of iron, or dogs, as they are called, sliding on the surface, their position being regulated by means of screws fixed in slots in the chuck, and gearing in nuts at the backs of the dogs. A cup chuck is a metal cup, having in its periphery six or eight set screws, by means of which articles to be turned or bored are held. This, like the other chucks, has an aperture bored through its centre, screwed inside, in order that it may be attached to the screw nose of the mandril.

Above the latter is shown the overhead driving gear. It con-

sists of a short shaft, supported in bearings, carried by two hanger brackets. On this shaft are fixed first, a pair of large fast and loose riggers; second, a pair of small riggers; thirdly, speed riggers. The latter are connected with the speed-riggers on the mandril of the front lathe head, whilst the fast and loose pulleys, large or small, as the case may be, are connected by a strap with the main driving shafts of the factory; when the lathe is to be driven, the strap is placed upon the fast pulley, which being firmly keyed to the short shaft, the latter is caused to revolve. When the lathe is to be stopped, the strap is shifted to the loose pulley. The strap is shifted by means of a fork, fixed on a sliding bar, as shown, which may be moved by means of a long lever or handle.

For boring large cylinders in the lathe, a boring bar is employed, being placed between the centres and within the cylinder to be bored, which latter is bolted down to the lathe bed. Upon the boring bar is a disc, called a boring head, which carries small cutters to operate upon the interior of the cylinder to be bored; it is moved longitudinally by means of a screw let into a groove in the boring bar, this screw being caused to revolve by means of gearing at one extremity. The lathe may be supported on iron frames or timber blocks as may be most convenient.

We will now proceed to describe the slotting or grooving machine, of which a view is shown (Plate V). This consists of a stout frame, carrying at its lower extremity a table, which admits of motion in three directions,—forwards, laterally, and a revolving motion. To the upper part of the frame guide blocks are attached, and within these guide blocks a square bar moves vertically. Motion is imparted to this bar or slide by means of a link, the upper extremity of which is attached to a pin, which forms the prolongation of a stud, bolted to the vertical slide, which stud is, however, adjustable by means of a screw working within the slide. The lower end of the link is attached to a pin capable of adjustment in a groove running diametrically across a disc. By the adjustment of the position of this pin on the disc, any stroke of the vertical slide up to about fourteen inches may be obtained. The grooved-disc is carried by the end of a shaft, to the other extremity of which is attached a large tooth or spur-wheel. This large spur-wheel gears with the pinion on the driving shaft, the motion of which is rendered more uniform by a fly-wheel firmly keyed on to

it. The apparatus is fitted with speed-riggers and overhead motion, similar in principle to those furnished to the lathe already described. On the secondary shaft, that which carries the grooved disc, is fixed a cam, as shown, consisting of a cylinder, having on its periphery a groove formed like a screw, returning into itself. This groove is fitted with a pin, carried at the extremity of one arm of a bell-crank. To the other arm of the bell-crank is attached by a pin a link, the lower extremity of which is connected with a second crank, carrying also a pall, by means of which a feed or self-acting motion is given to the table for the machine; for as the cam revolves the pall moves backwards and forwards, sliding over the teeth of the wheel in one direction, and pushing the wheel before it on its return. The wheel can thus be made to revolve by intermittent movements in either direction, by turning the pall on either side of the centre as may be required, or, if necessary, the pall can be thrown out of gear altogether. There is another link proceeding from the bell-crank, which carries this pall to an arm working upon the centre of another wheel, which is also fitted with a pall, in order to obtain self-acting motion of the table laterally. To the lower extremity of the vertical slide are fitted two clamps for holding the cutting tool as shown. The machine here illustrated admits of articles of very large diameter, nearly eight feet, being intended to slot railway wheels; but for other purposes similar apparatus are made with less clearance.

Plate VII. exhibits a very simple but useful form of shaping machines. It consists of a stout table or foundation-piece, to one side of which is attached a table or chuck, to hold work whilst it is undergoing the process of planing. This table may be raised and lowered by means of a vertical screw, being kept in position by guide blocks working in two vertical screws. To the opposite side of the foundation-piece brackets are attached, carrying a short shaft, on which speed-riggers and spur-wheels are fixed. One of those spur-wheels gears in a larger wheel placed above and behind it. This wheel is fixed on a shaft carrying a slotted disc, which, by means of a link, similar to that described as appertaining to the slotting machine, drives a horizontal slide. To the extremity of this slide, by means of set screws, shown, the cutting tool is held in a frame capable of oscillating on an axis, in order to allow the cutting tool to rise on the return stroke, thereby pre-

venting the risk of breakage. The tool is capable of adjustment vertically by a vertical screw, and angularly by a tangent screw and quadrant, as shown in the front elevation. The horizontal slide, with the cutting tool and gearing, admits of a lateral motion, being fitted accurately to the upper surface of the foundation-piece, this lateral motion being imparted to it by means of a screw and nut. All the movements in this machine may, if it is desired, be fitted with feeds, in order to render it self-acting. We may here observe that the grooves in the chuck or table are undercut, in order to admit the heads of bolts, whereby the work is securely fixed. The usual driving gear is furnished to this machine.

We will now proceed with the description of a drilling machine, illustrated Plate VIII. This machine consists of a stout frame, carrying at its lower part a table or chuck capable of vertical motion, and at its upper part two arms, supporting the drilling gear. The driving riggers and accompanying gearing are similar to that exhibited on the head stock of the lathe previously described; but motion is communicated from the horizontal mandril to the vertical spindle by means of bevelled or mitred wheels, as shown. The vertical spindle is hollow, containing the drilling shaft, which has at its lower extremity a socket for the drills, and at its upper extremity a screw by which it is raised or lowered. At the back end of the horizontal driving shaft are some small speed pulleys connected by a strap with a similar series on a parallel shaft placed lower down, and having at its front extremity a short screw, which gears with a worm-wheel on the lower end of a vertical shaft, parallel with the drilling spindle. The upper end of this shaft carries a spur-wheel, which gears with another fixed to the nut, by which the screw attached to the upper end of the drilling spindle is raised or lowered; thus the machine is made self-acting. To the lower end of the smaller vertical shaft is fixed, as shown, a hand-wheel, so that the feed may be applied by hand, if required. This machine may be used either with drills or small boring bars, carrying cutters fixed in slots. The driving gear is of the usual form.

Plate IX. represents a planing machine. It consists of a stout bed or foundation-piece, furnished with two grooves. Upon this bed slides a table furnished with pieces, which fit the grooves. This table is caused to move rectilinearly by a pinion acting upon a rack attached to its lower side. This pinion is driven by gear-

ing connecting it with a driving shaft having three wheels or riggers, the centre one being loose and the outer two being so arranged that when the strap is on one wheel a slow motion towards the cutting-tool is obtained, and when it is upon the other wheel a rapid motion from the cutting-tool is obtained. The strap is shifted at the end of each stroke by means of a pair of stops, clamped to the bottom of the table. These stops strike an arm on a shaft, throwing it backwards and forwards, whereby the motion is reversed and the requisite feed imparted to the cutting tool. Near one end of the bed a pair of stout frames are fixed, one on each side, connected at the top by a strong bracing piece. The front faces of the upright posts of these frames are accurately finished, and carry a long transverse slide, which may be raised or lowered by means of vertical screws outside the post, worked by bevel wheels gearing into others, fixed on a transverse shaft passing over the top of the frames. On the centre of the transverse slide is the tool-holder, fitted on a slide with a vertical adjustment, and also an angular adjustment. This slide may be moved horizontally or vertically by the self-feeding apparatus mentioned above; the former being obtained by means of a screw in the transverse slide, and the latter by a sliding bevel-wheel on a shaft in the same, which gears with another bevel-wheel on the vertical adjusting screw of the tool-holder. In this apparatus, as in the shaping machine, the tool rises at the return stroke of the table, the tool-holder working upon gudgeons. In order to plane the sides of wide work, tool-holders are attached to the vertical posts of the side frames or standards. The feed is applied by means of palls, the arms to which they are attached being worked by a vertical rod, which rises and falls according to the motion of the shaft, by which the strap is shifted at the termination of each stroke.

Plate X. exhibits a view of a punching machine of peculiar construction. On one side of the apparatus is a punching, on the other side a shearing, arrangement. These are worked by levers, as shown, the punch and upper shearing edge being alternately raised and lowered by means of the cams, shown in dotted lines. These cams are upon a shaft carrying a large spur-wheel, to which motion is communicated by a pinion on the driving shaft.

Punching and shearing machines are generally made with ver-

tical slides, as in the above apparatus; which, however, are driven by eccentrics working in rectangular spaces within them, of such dimensions that the width of the aperture allows for the lateral play of the eccentric; whereas the height of the aperture is equal to the diameter of the eccentric.

Messrs. C. De Bergue and Co. have patented an exceedingly ingenious punching and shearing machine. It consists mainly of a stout frame, containing within it a rocking-frame worked by an eccentric. The lower part of this frame is wide, carrying on one side a shearing edge, on the other a punch.

Mr. Cochrane, of the Woodside Iron-works, Dudley, has constructed some drilling machines, containing eighty drills each, to drill the plates of the railway bridge now in construction at Charing Cross. The feed is applied by hydraulic pressure. It has been found that with eighty one-inch drills plates five eighths of an inch could be economically perforated in fifteen minutes.

Besides the machinery already noticed, machines are made in which nuts and screws can be produced. They are fitted with easily moved slide rests, which rests are drawn along by the action of the threads following the cutting edges.

The nut-shaping machine consists of a table, to which is fitted a head stock and driving gear; upon the mandril is a rotatory cutter, with cutting edges on its face and also on its periphery. In front of this cutter is a circular piece of metal, formed with six or eight equidistant notches in its edge, into which a pall may be caused to fall, to retain the plate or chuck during the operation of facing one side. The top of the nut is faced by the periphery.

A dividing engine is a species of lathe with a divided chuck, palls falling into the divisions.

In addition to the machines described, other apparatus are frequently required for the execution of work of a peculiar character.

Some minor machines will be described whilst treating of the manipulations conducted in the workshop.

# CHAPTER VI.

## ON MANIPULATION.

In the present chapter we purpose to describe the manipulations with which the mechanical engineer must be acquainted in order to reduce rough castings and forgings to accurate forms, and to fit together and erect the machines of which those forms are the elements.

The most convenient method of describing these manipulations will be to commence with the rough castings and forgings, and follow them through the various processes which they must undergo previous to their completion. Let us commence with the casting of a steam-engine cylinder, with its covers and slides. The cylinder may first be fixed upon the bed of the lathe and bored, the boring being effected in the following manner. Let the boring-bar be placed between the centres, and fitted with a boring-head, in diameter nearly equal to the internal diameter of the cylinder. In this boring-head several cutters are fixed, the angles of the cutting edges being nearly 90°. By this means we may remove the greater portion of the excess of the material; but in taking the last cut, the lathe must not be stopped after the commencement of the cut until the completion of the same, and the cut should be taken by a point-tool, which will give most accurate results; for although the interior of the cylinder may look and feel rough, it will be found after a few days of active working to have worn smooth, which will not occur so satisfactorily if the cylinder be improperly bored.

The ends or flanges of the cylinder may also be faced up before removing it from the lathe by cutters fixed to a slide attached to the boring-head.

The cylinder having been bored, it may be removed to the planing machine, where the port faces may be planed; in this, as in

the last operation, the finishing cut should be taken by a point-tool. These port faces will subsequently require further treatment to reduce them to a plane surface as nearly as possible; but we will now consider the preparation of the cylinder covers.

Each cylinder cover may be chucked in an ordinary lathe, turned on the edge, faced on the under side of the flange, and the upper cover bored out at the stuffing-box. The covers may then be placed in position upon the cylinder, and the holes by which they are to be connected with the latter drilled under the drilling-machine.

We will next speak of the operation of facing the ports; we must, however, first pause to mention the instruments used by the engineer to measure and mark out his work. The first of these, the dividers or compasses, are too well known to need any description at our hands. The callipers, intended for taking diameters and thicknesses, are similar to compasses, with curved legs; for taking thicknesses and diameters external, the legs should be bowed outwards, but for taking the width of recesses and internal diameters, they should be bowed inwards; but one pair may be made to answer both purposes. The mechanic will also require squares, straight-edges, and planometers, or surface-plates. Squares may be tested by ruling a very fine line, holding the pencil close against the edge of the square, then reversing the square, and drawing another fine line coinciding at some point with the former; then if the lines coincide throughout, the square is correct, if not, the contrary is the case. The straightness of the blade of the square may be tested in the same way as that of an ordinary straight-edge, which is effected thus: rule a line as before, after which turn the straight-edge end for end, make the two ends of the straight-edge coincide with the extremities of the line already ruled, then rule another fine line; if this coincides in every part of its length with the first line, then is the straight-edge accurate, but if otherwise, the two lines will contain a space, and as two straight lines cannot contain a space, the edge must be inaccurate.

It may be interesting here to describe the method to be pursued in making a straight-edge. Three straight-edges should be made together; for this purpose three strips of metal are laid side by side, and planed as true as possible; we will number them one, two, and three. In the first place, numbers one and two are filed

and scraped until they accurately fit each other, so that, when held up to the light, no light can be seen between them. Numbers one and three and two and three must also be made to agree; then, when any two of the straight-edges, taken indiscriminately, accurately coincide, all the straight-edges are perfectly true.

We will now proceed to describe the planometer, or surface-plate, in reference to its construction and use. Two should be made together; they should consist of a flat cast-iron plate, supported by webs at the back; the two plates are planed with a point tool, then filed and scraped until, if a straight-edge be laid upon one in any position, the light cannot be seen between the straight-edge and surface-plate. Ruddle, or other red coloring-matter, is then rubbed upon one of the two surface-plates, and the other surface-plate is placed upon it and moved about, when it is evident the highest points, or points of contact of the two plates, will be colored; these are scraped down, and the process repeated continually, until upon rubbing the plates together the coloring-matter becomes uniformly distributed upon the entire surface.

In the same manner as the planometer is made, the port-faces of the steam-cylinder are made true, ruddle being rubbed on the planometer, which is then moved about upon the port-face; the parts of the port-face which become colored represent the highest points, which are therefore scraped down, and the process repeated continually until the bearing is uniform, which is indicated by uniformity of the color taken up by the port-face. The slide which moves upon the port-face is then, by means of the planometer, brought to as true a surface as possible, after which the slide and port-face are by a similar method made to bear accurately upon each other.

If any part of the cylinder be of intricate curved form, the shaping machine may in many cases be employed with advantage to operate upon such part; if, however, this apparatus is not applicable, then must the surface be finished by hand.

We now proceed to consider the completion of the piston and piston rod. The body of the piston will consist of a short cylindrical piece, or disc, having on its lower surface a flange and being fitted at its upper surface with a movable flange, called a junk-ring, this junk-ring being retained in position by bolts. Between the two flanges, and around the body of the piston, are

placed elastic packing-rings of cast-iron; these rings are cut thicker on one side than on the other, in order that they may be equally elastic all round. The upper and lower surfaces of these rings must be accurately fitted by scraping to the flanges of the piston; the body of the piston is bored in the centre in order to allow of the attachment of the piston-rod, which is fixed in position by a bolt, or nut, or by a key, or other convenient means.

We next come to the construction of the piston-rod, which is usually made of round iron. A piece of suitable dimensions having been chosen, the centre of each extremity is found as nearly as possible, marked with a centre-punch, and by the indentations thus made the bar is suspended between the lathe-centres and caused to revolve while a piece of chalk is held against it. If it does not run truly between the lathe-centres, the highest parts will be indicated by a chalk-mark. The bar is then removed from the lathe and recentred, and the operation repeated until the centres are sufficiently accurate in position, after which a ring is passed over one end of the bar, and firmly held upon it by means of a set screw: this ring has at one part of its periphery an arm, and is called a carrier. The bar is then replaced in the lathe, with the carrier next to the chuck on the lathe mandril, so that the work may be caused to revolve by means of a bolt attached to the chuck, which comes in contact with the arm on the carrier.

The greater part of the superfluous metal is then removed at one cut by means of a point tool, after which the remainder of the metal over and above the necessary quantity is removed by a lighter cut, when the piston rod may be fitted to the piston.

We will now describe the remaining implements used by the fitter and erecter for the completion of work which has already been operated upon in the lathe or other machine.

The first and most indispensable piece of apparatus is the tail-vice, or smith's vice, shown Fig. 23. It consists of a large vice with long jaws, one of which is prolonged into a tail, the lower extremity of the tail being fixed in a block attached to the floor; at the upper part of the vice, just beneath the screw by which the jaws are closed, is a strip of iron, by means of which the vice is firmly screwed to the work-bench. The vice should be furnished with pieces of tin and copper, to hold work which would

be damaged by the teeth of the vice; also, for a similar purpose, clams should be made of an alloy consisting of nine and a half parts of lead to one part of antimony.

Fig. 23.

The fitter and erecter will also require a scribing-block, which consists of a piece of metal jointed to a wooden block at one end, and having at the other a point; it is useful for marking centres, and for similar purposes.

In filing flat surfaces considerable practice is required, in order to avoid rounding them, in which consists the proper use of the file; and this is a matter in which nothing short of actual experience can be of any value, hence we shall not further dilate upon it.

In fitting round surfaces, such as a shaft to its bearings, a method somewhat similar to that used for truing plane surfaces is used; the shaft is turned and the bearings are bored as accurately as possible, after which some ruddle is rubbed upon the shaft, which is then worked in contact with the bearings. By this means the first points of contact are indicated, which are scraped down, and the process repeated until a sufficient degree of accuracy is attained.

In conclusion of these brief remarks upon manipulation, we may observe that in erecting machinery it is very necessary to have marks upon various parts in line with each other, in order to supply a means of determining whether any settlement or other derangement occurs subsequently.

## CHAPTER VII.

### ON THE PHYSICAL BASIS OF THE STEAM-ENGINE.*

In the present chapter we purpose to treat of the physical basis of the steam-engine, or in other words to examine the physical force upon which the action of the steam-engine depends, this force being heat.

With regard to the theory of heat, we cannot prove, certainly, in what heat consists; but it seems highly probable that it consists in motion of the atoms of which various bodies are composed. The ordinary effects of heat, such as expansion, contraction, liquefaction, and volatilization, are too well known to require any account at our hands; but we have yet to explain the circumstances under which these phenomena take place.

We must first mention the manner in which heat is conveyed from place to place. This may occur in three different ways,—by radiation, by conduction, and by convection. By the first method we understand the heat to be propagated through gaseous matter; thus, if we hold our hand in the neighborhood of a heated body we experience a sensation of warmth, the heat being radiated, as it is termed, through the air and communicated to the hand. The term conduction signifies the passage of heat through a solid body; thus if we place the end of a bar of metal in a furnace, keeping hold of the other end, we shall, after a short space of time, find that the heat has passed along the bar and is communicated to the hand. Let us now compare these processes of radiation and conduction in order to determine in what relation they stand to each other. If we accept the dynamic theory of heat, the following explanation will hold good. In the case of radiation in the example first mentioned, the atoms of which the heated body consists are moving within a certain limited sphere with an abnormal velocity, the sphere being increased according to the

* See Preface.

velocity with which they move, thus creating expansion; these atoms communicate motion to the neighboring atoms of the circumambient air, which communicate their motion to other atoms of air, until the hand is reached. In the second example, the movement of the heated particles in the furnace is communicated to the nearest atoms of the bar of iron, from these to the next, and so on to the farther extremity. These two examples differ only in the medium through which the heat is propagated,—in the one case it is gaseous, and in the other it is solid, but in both cases the method of propagation appears similar. A portion of the heat is, however, carried off by the heated particles of air by the method of convection which we will now proceed to describe.

Let us suppose that we apply heat to a liquid, say water, we shall find that the heated particles will rise to the surface, being replaced by cooler ones: thus the heat is conveyed away, the heated particles passing away from the source of heat. A similar result occurs when gases are heated, an upward current being created. The motion of the particles away from the source of heat in the case of convection, is easy of explanation according to the dynamic theory. We may suppose that the atoms nearest the source of heat, when their temperature is raised, revolve in their spheres with increased rapidity, at the same time increasing the range of their sphere of rotation; thus, a fewer number of atoms will be contained in a given bulk at any given temperature, than will be contained in the same bulk at a lower temperature; hence the specific gravity of the heated liquid will be less than that of the cool liquid, wherefore the former will rise to the surface of the latter with a velocity proportional to the difference of temperature, thus producing the phenomena of convection.

We may next speak of the so-called latent heat, a term which we consider as tending to lead to erroneous conclusions.

If we evaporate say one ounce of water, and cause the whole of the resulting one ounce of steam to pass into cold water, we shall find that it is capable of raising five or six ounces of water to the boiling-point. At first sight this appears somewhat inexplicable, for we have one ounce of water raised to a temperature of 212°, and evaporated from that temperature, yielding one ounce of steam also at 212°, yet when this one ounce of steam is condensed, the heat contained in it is found capable of raising five

or six ounces of water at a normal temperature to the boiling-point, 212°; thus the steam has yielded in condensation about 1000° of temperature beyond that indicated by the thermometer. That the steam contained that heat was certain, and also that its presence could not be determined in a direct manner, and at the same time the duty done by such heat did not appear evident to the discoverer of the fact; hence, this 1000° of heat being hidden as it were in the steam, was called latent heat. It appears, however, that this heat is absorbed in changing the physical condition of the aqueous particles, being recovered when those particles are restored to their original condition.

It is also observed that whenever a body is expanded, heat disappears, or is absorbed by that body; and whenever a body is condensed, heat is evolved. And the converse also holds good: whenever heat is evolved condensation takes place; and whenever heat is absorbed expansion takes place. As an example of the first case, let us suppose a vessel to be filled with compressed air or steam, and allow this air or steam to issue through an aperture, then as it passes into the atmosphere it will be relieved from pressure, and will therefore expand, and upon holding the hand in the current of air, a cooling influence will be felt, the air in its expansion absorbing heat from the hand. The same will take place in the case of the jet of steam, which is more curious, because the steam exists at a much higher temperature than the air. This result, viz., the cooling influence of a jet of steam, is not obtained unless steam of a high pressure be used.

With regard to the evolution of heat under the case of condensation, we might quote many instances as examples; the condensation of steam is, however, sufficient for our purpose.

We may quote one example in support of the statement that wherever heat is evolved condensation takes place. This examination consists in the combustion of a jet of hydrogen gas in an atmosphere of oxygen; in this case a very great degree of heat is evolved, as is observed in the case of the oxyhydrogen blowpipe, and a very great degree of condensation occurs; the amount may be imagined from the following approximate figures: To produce one cubic inch of water, nine hundred cubic inches of oxygen and eighteen hundred cubic inches of hydrogen will be

required; thus a bulk of two thousand seven hundred cubic inches of gas is condensed into one cubic inch of water.

With regard to the absorption of heat occurring in conjunction with the expansion of bodies, we may refer to volatilization, which never takes place without a certain quantity of heat being absorbed over and above that which is indicated by the thermometer.

We will next proceed to speak of what is termed specific heat. We may illustrate the meaning of this term most clearly by taking an example. Let us suppose that a certain quantity of hydrogen gas must be burnt to raise a pound of water 10°, then the combustion of the same quantity of hydrogen will raise eight pounds of iron 10°; we therefore say, that the specific heat of iron is 0·125 or $\frac{1}{8}$, if that of water is called 1 or unity.

From researches on heat, Petit and Dulong have deduced a law that the specific heat is the same for the atoms of all simple bodies, and this law is to a certain extent borne out by experiment.

We will now pass on to the transformation of heat into work or motion.

Heat and motion being mutually transformable into each other, it would appear that some constant ratio should exist between the quantity of heat and the work effected by it, or between the amount of work required to evolve a certain amount of heat and the heat evolved by such work; or in other words, that some mechanical equivalent to heat should exist. It is perhaps necessary here to mention what is meant by the term work, in its real sense; it is a force exerted through a space, and the intensity of the force, multiplied by the space through which it acts, is equal to the work done; and in this consists the difference between dynamic and static force, for the latter is a force at rest, or a pressure which is balanced by some other equivalent pressure, or by a number of pressures, of which the resultant is equivalent to it; but in the case of dynamic force the pressure is not so balanced, and in consequence, motion is produced.

The amount of work executed in any particular case we shall state in foot-pounds,—that is to say, we shall obtain our valuation of the work done by multiplying the force in pounds by the distance it passes through in feet. Thus, if a force of weight equal to 30 pounds is caused to act through a distance of 12 ft., the

work done will amount to 360 ft.-lbs.; also, if a force equal to 60 pounds is caused to act through a distance of 6 feet, we shall also obtain an amount of work equal to 360 ft.-lbs. We will now return to the mechanical equivalent of heat. Dr. Joule some time since made some careful experiments in order to determine the mechanical equivalent of heat, and the conclusion at which he arrived was that 772 ft.-lbs. are equivalent to that quantity of heat which is requisite to raise one pound of water 1° Fahrenheit, this quantity of heat being adopted as the unit or measure, in the same way as one inch is considered the measure of length, or one cubic inch is considered a measure of volume.

772 ft.-lbs. is, then, the quantity of mechanical work which we might expect to gain for every equivalent of heat, but our machinery is so imperfect that we do not realize this amount.

The method by means of which we make available to our requirements the dynamic force of heat, usually consists in the employment of the elastic or expansive force of some gas or vapor which has previously been produced in, or compressed into, a space less than that which it would occupy at a normal pressure. When steam is used, the requisite pressure is obtained by generating steam from water contained in a close vessel, such steam accumulating until the required tension is obtained: and the amount of steam generated will be found to exceed the bulk of water evaporated to produce it in the ratio of about seventeen hundred volumes for one at the ordinary atmospheric pressure. At twice this pressure the volume will be reduced to about half; at four times the pressure to nearly a quarter; and so forth.

If we have steam of a pressure of four atmospheres acting beneath a piston fitted in a cylinder, so that it can rise or fall, air and steam-tight, the top of the cylinder being open, then it is evident that the pressure beneath the piston will be four times as great as that above it, wherefore the piston will rise with a force equivalent to three atmospheres. The pressure of the atmosphere is about 14·7 lbs. per square inch; but it may be taken in round figures at 15 lbs. per square inch.

It is in this difference between the pressures on the two sides of a piston made as nearly as possible air and steam-tight, that the mechanical principle common to all steam-engines consists.

There are two ways of working the steam-engine, expansively

and non-expansively; and the engines are divided into two classes, condensing and non-condensing. In the former a vacuum is made on that side of the piston opposite to the steam side, by condensing the steam which previously occupied that space; whereas in the non-condensing engines the steam acts on one side of the piston, and the atmosphere on the other.

We will now speak of the two ways of working engines. By the first method, the non-expansive steam of the full pressure is admitted during the whole of the stroke of the piston,—that is to say, during the time of its passage from one end of the cylinder to the other. Whereas by the second method, the steam is shut off when a part only of the stroke is performed, the remainder being executed by the expansion of the steam already admitted to the cylinder.

It is generally held that the expansive method of working is by far the most economical; but experiments have recently been performed by Stimers, Isherwood, and others, upon an American vessel, the results of these experiments being in favor of the non-expansive system of working. It is however necessary to examine with care these experiments, in order to determine whether they afford really a sound proof of the inefficiency of the expansive mode of working. We find that in some cases the quantity of steam required was more when expansion in a high degree was employed, than when a low rate of expansion was used; thus when the steam was cut off at $\frac{1}{2}$ of the stroke, the consumption was 32 lbs. of steam per horse-power per hour; but for $\frac{7}{10}$ it was 33 lbs., and for $\frac{3}{10}$ 34 lbs. These are not exactly the quantities used, the decimals having been omitted; but they are sufficiently accurate for our purpose. This, however, only leads us to conclude that under the circumstances a moderate degree of expansion was found more economical than an extreme degree of expansion, which is not very easily accounted for, the following calculation appearing to show that the higher the degree of expansion employed, the greater should be the economy obtained.*

Let us suppose that we have a steam-cylinder fitted with a piston, the area of which is 100 square inches, and let us have steam at a

* The manner in which the experiments are reported prevents our examining them thoroughly; also several experiments were not reported at all, and the same furnace was used at different rates of firing.

pressure of 60 lbs. to work with; suppose we allow the full pressure of the steam to act through half the stroke, the entire stroke being 2 ft., then the units of work executed during this half stroke will be the area of the piston, multiplied by the pressure per square inch, multiplied by the space passed through, which will be equal to 6000 ft.-lbs. Let us suppose the steam to be now cut off, then the steam in the cylinder will expand to the end of the stroke; being reduced to about its normal pressure, and occupying twice its original bulk, the effective work being equal to the mean pressure on the piston during the half stroke: multiplied by the area of the piston and the distance passed through, the mean pressure will be rather less than half the sum of the pressures at the moment of cut-off and at the termination of the stroke; this sum will be 90 lbs. Let us call the mean pressure 40 lbs., then the amount of work executed by the expansion of the steam will be 4000 ft.-lbs., about $\frac{2}{3}$ of that effected by the full pressure steam acting through the same space. The amount of work executed by one cylinder full of steam cut off at half stroke will be 20,000 ft.-lbs. If we use the steam at full pressure throughout the stroke, the amount of work executed by one cylinder full should be 12,000 ft.-lbs., $\frac{3}{5}$ of that executed by the same quantity of steam working at the above degree of expansion. It also further appears that all work done after the steam is cut off, is so much actual gain, as, if the steam were allowed to escape at full pressure, the work capable of being executed by its expansion would, of course, be lost. How, then, are we to account for a loss of economy when a high degree of expansion is used? Let us examine more closely into the conditions of the experiments quoted above, in order to see whether we cannot account for this loss. We find that the steam-pressure employed was certainly low, commencing with about 34 lbs. per square inch, and in extreme cases being expanded down to a pressure of 5·9 lbs. per square inch, in which case the temperature of the steam would be reduced from 279° down to about 229°; this reduction of temperature would of course cool the surrounding metal, which, in its turn, will abstract heat from the steam admitted to the cylinder at the next stroke, thereby causing a loss, this loss varying in proportion to the difference of temperature of the steam entering and leaving the cylinder. By using steam of a higher pressure in the same cylinder, the proportionate loss will not be so great, for although the

loss expressed in degrees will be greater in proportion, the quantity of steam in the cylinder will also be greater; this point may, however, be more readily explained by an example. If steam be expanded from 30 lbs. pressure to 5 lbs. pressure, there is a loss of temperature of 48°. The number of units of heat abstracted from the metal will of course be proportional to this quantity, and the quantity of heat which the cool metal will absorb from the hot steam will also be proportional to the same quantity. If we expand steam at 60 lbs. down to 10 lbs., the loss of heat will be 67°, and the quantity abstracted from the hot steam at the next stroke will be proportional to this; but the quantity of metal has remained constant, whereas the weight of the steam is doubled: hence; to heat the metal 48°, steam at 30 lbs. pressure will have to yield 11 units of heat, whereas to heat the metal 67°, steam at a pressure of 60 lbs. per square inch would only have to lose 7 units. These considerations tend to show that the experiments give results which are reliable only under the circumstances under which they are conducted, and that steam of a higher pressure or engines differently constructed will give different results.

Some well-conducted experiments on the relations of heat to steam and mechanical work are now very much wanted, and it appears to us that these experiments should be performed with apparatus of very accurate construction, admitting of a great variety of pressures, and also allowing of variations in the general circumstances, in order that the quantity of heat lost by radiation and conduction may be estimated.

We may here remark upon the use of other gases besides steam to propel thermo-dynamic engines. The most important of these applications consists in the employment of atmospheric air, and the air or caloric engines appears in many respects to have the advantage over steam-engines: the principle of working is of course similar, that is to say, the air is expanded by heat in order to obtain pressure.

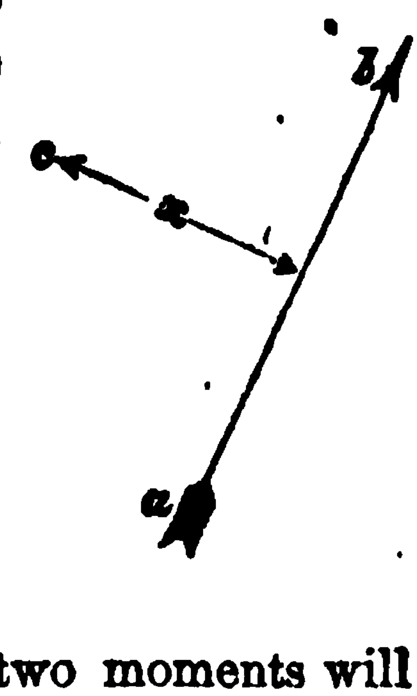
Engines propelled by ether have also been proposed, but we are not aware that they have been found practically useful. We would in concluding this chapter recommend our readers to examine C. W. Williams's theory of the evaporation of water; which we have refrained from discussing in these pages, as it is as yet not established, although there are many points of importance which may be decided without very great difficulty.

# CHAPTER VIII.

## ON THE PRINCIPLES OF MECHANICAL CONSTRUCTION.

We will now give a brief account of mechanics as applied to the construction of machinery, commencing with an account of the means of concentrating power. We will take as an example the ordinary lever. It will first be necessary to consider the manner in which a force acts round a centre. Let us suppose a force of 10 lbs. to act perpendicularly on one end of a bar, of which the other end is carried upon a centre, then the revolving force upon that centre will be proportional to the intensity of the weight or force, and to its distance from the centre. Let the bar be 6 feet long, then the relative intensity of the revolving force may be represented by 60 ft.-lbs. This revolving force is called a moment. We may find an equivalent moment by using a weight of 6 lbs. and a 10 ft. bar, for the moment in this case will also be 60 ft.-lbs. The general rule to find the moment of any given force about any given point will be, multiply the intensity of the force by its distance from the point measured perpendicularly to the direction of the force. In Fig. 24 we illustrate the manner in which this distance is measured. A force $w$ acts in the direction $a\,b$; it is required to find its moment about the point $c$; from $c$ let fall a perpendicular upon $a\,b$, and call the length of this perpendicular $x$, then will the moment of the weight about $c$

Fig. 24.




$$= wx.$$

From the above remarks it appears that any two moments will be equal, when the distances of the weights producing them from the centres to which they are referred, vary inversely as the weights. Suppose this condition to be fulfilled, and let the

moments act about the same centre, but in opposite directions; then will a condition of equilibrium be attained, and in this balance of moments it is that the principle of the lever consists.

Let us suppose that we have an ordinary bar supported at one third of its length upon a pin or gudgeon, about which it is free to revolve, the weight of the bar being at present neglected, and let the length of the bar be 9 ft., then, on one side of the centre, pin, or fulcrum, as it is termed, there will be a length of 6 ft., and on the other a length of 3 ft.; let a weight equal to 500 lbs. be attached to the shorter end, it is required to find the weight which must be attached to the longer end in order to balance this weight. The weights and their distances must vary inversely as each other; hence we may solve this question by proportion, thus—

$$6 : 3 :: 500 : 250.$$

250 lbs. will therefore be the weight required. We may give as the general rule for solving similar questions the following. To find the weight which, attached to one arm of a given lever, will balance a known weight attached to the other arm, multiply the weight by the length of the arm supporting it and divide the product by the length of the other arm, the quotient will be the quantity required. Thus in the above case we have—

$$500 \times \tfrac{3}{6} = 250.$$

This rule will apply to every kind of lever, care being taken to observe the conditions under which it acts; its principle, however, is the same whether the arms be in a straight line with each other, or whether they be parallel or contain an angle, and if the length of the arms remains constant, the same forces will maintain equilibrium. Various forms of levers are shown, Fig. 25, but the same length of arms is preserved in every case. We may here observe that the proportions between the weights and arms refer to relative quantities, and not to absolute; thus a lever having arms 3 ft. and 6 ft. long will have the same value as one with arms 4 ft. and 8 ft. long, for the proportion of the arms is the same in both cases, as shown by the following equation—

$$\tfrac{6}{3} = 2 = \tfrac{8}{4}$$

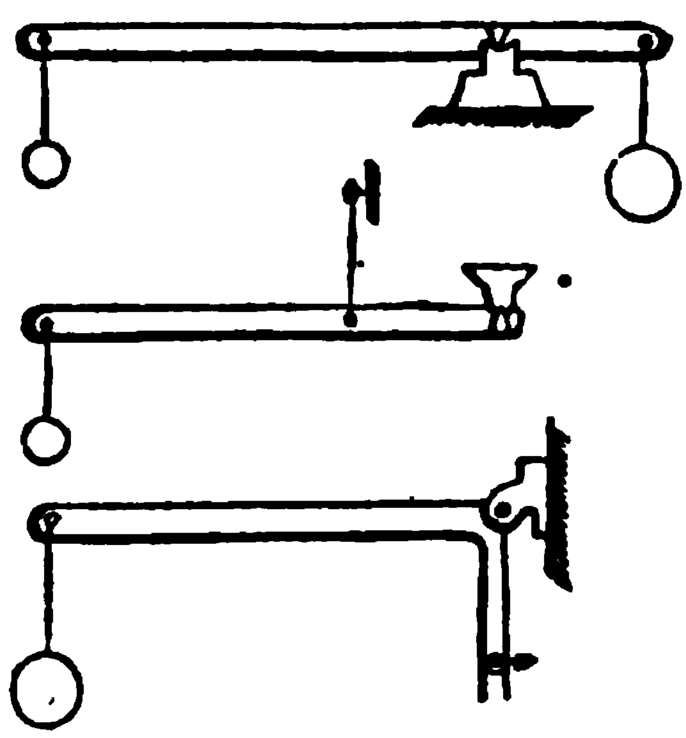
Let us now compare the work performed when the arms move about the fulcrum in the case of the lever mentioned above. Let

the long arm move through 1 ft., then the amount of work executed will be

$$250 \times 1 = 250 \text{ ft.-lbs.}$$

Let us now examine the amount of work executed at the same time at the other end of the lever. We must first find the space

Fig. 25.



through which the end of the short arm will move, whilst that of the long arm moves through 1 ft. The ends of the arms describe circles about the fulcrum; hence, in moving through the space mentioned above, a part of the circumference of a circle will be described, and the distance passed through will vary as the length of the arms which are the radii of the circular arcs; hence, the end of the short arm, which carries the 500 lb. weight, will move through half the space of the long arm, or through $\frac{1}{2}$ ft., the lengths of the arms being 6 ft. and 3 ft., and the amount of work performed at the extremity of the short arm will be

$$500 \times \tfrac{1}{2} = 250 \text{ ft.-lbs.},$$

which is equal to that performed at the end of the long arm.

From the above observations, we find that by means of a lever we may raise a given weight by a force equivalent to a much smaller weight, but at the expense of time; hence, in this case power is not gained, but a force expended during a certain time is concentrated to overcome a greater force, the static forces being unequal, but the quantity of work done by them in a given time being equal.

We may now generalize the results of the investigation of the laws of the lever, in order to apply it to other machines for con-

centrating power in the following manner:—In any machine let $x$ represent the distance through which a given force is to be exerted, or through which an equivalent weight is to be lifted. Let $w$ equal this weight or force; let $y$ equal the distance through which the pressure required to raise it will move in the same time that $w$ will move through $x$, $w'$ being equal to the pressure, then the amount of work to be executed will be

$$= wx,$$

the work done by the motive power will be

$$= w'y$$

These two quantities must be equal, or rather, to produce motion, one must preponderate by an infinitely small quantity, otherwise the apparatus will remain in equilibrio; the balancing forces may be found from the following equations:

$$wx = w'y$$

$$w' = w\frac{x}{y}$$

$$w = w'\frac{y}{x}$$

$$x = y\frac{w'}{w}$$

$$y = x\frac{w}{w'}$$

These equations will of course apply to simple or complicated machines, where an uniform resistance is overcome by an uniform force, $x$ being the distance through which the point of resistance moves in a given time, and $y$ the distance through which the point of application of the power moves in the same time.

The pulley and axle are evidently identical in their action with the two arms of a lever. The screw and inclined plane act differently, but the law given above will of course be applicable, the distances moved through being very easily found; thus, when a single threaded screw revolves once, any body whichi s being raised by it passes through a distance equal to that between two threads of the screw measured from centre to centre.

We may now instance another means of concentrating power, viz., by hydraulic pressure. Let $a$ and $b$, Fig. 28, represent two

cylinders, each accurately fitted with a piston, as shown, the lower parts of the cylinders being filled with water, and communicating with each other by means of a pipe. Let the diameter of *a* be

Fig. 26.

twice that of *b*, then, because the areas of circles vary as the squares of their diameters, the area of the cylinder *a*, or of the piston contained by it, will be four times that of *b*. If we cause the piston in *b* to descend through a distance of, say 2 inches, a layer of water two inches thick will be displaced from the cylinder *b*, and forced into the cylinder *a*, where, however, it will spread out so as to cover four times the area which it did when in *b*; hence, the stratum, or layer, will have only one quarter of the thickness, and the piston in *a* will rise through one quarter the distance that the piston in *b* is moved through; hence, a weight on the piston in *b* will balance a weight four times as great placed on the piston in *a*. This may be shown also by the following method of reasoning. If a pressure of $x$ lbs. per square inch be imparted to the water contained in the two cylinders, the water will react in every direction, vertically, horizontally, and obliquely, with a force equal to 1 lb. per square inch; but the area of the large piston is four times that of the small, or contains four times as many square inches, therefore, as the total pressure on each piston is equal to the pressure per square inch, multiplied by the number of square inches of surface of the piston, the water will exercise four times the pressure on the large piston that it does on the small, or, 1 lb. on the small piston will balance 4 lbs. on the large piston.

This principle is taken advantage of in the hydrostatic press.

where a large force is exerted by means of a large piston working in a cylinder, into which water is forced by a pump of small diameter; the conçentration of power obtained by these machines may be found by the following equations. Let $f$ equal the force applied on the pump piston, $d$ equal the diameter of the pump piston, and $d'$ equal the diameter of the ram, or piston through which the force is to be applied, $p$ equal pressure exerted by the ram, then

$$p = f\frac{d'^2}{d^2}$$

$$f = p\frac{d^2}{d'^2}$$

$$d = d'\sqrt{\frac{f}{p}}$$

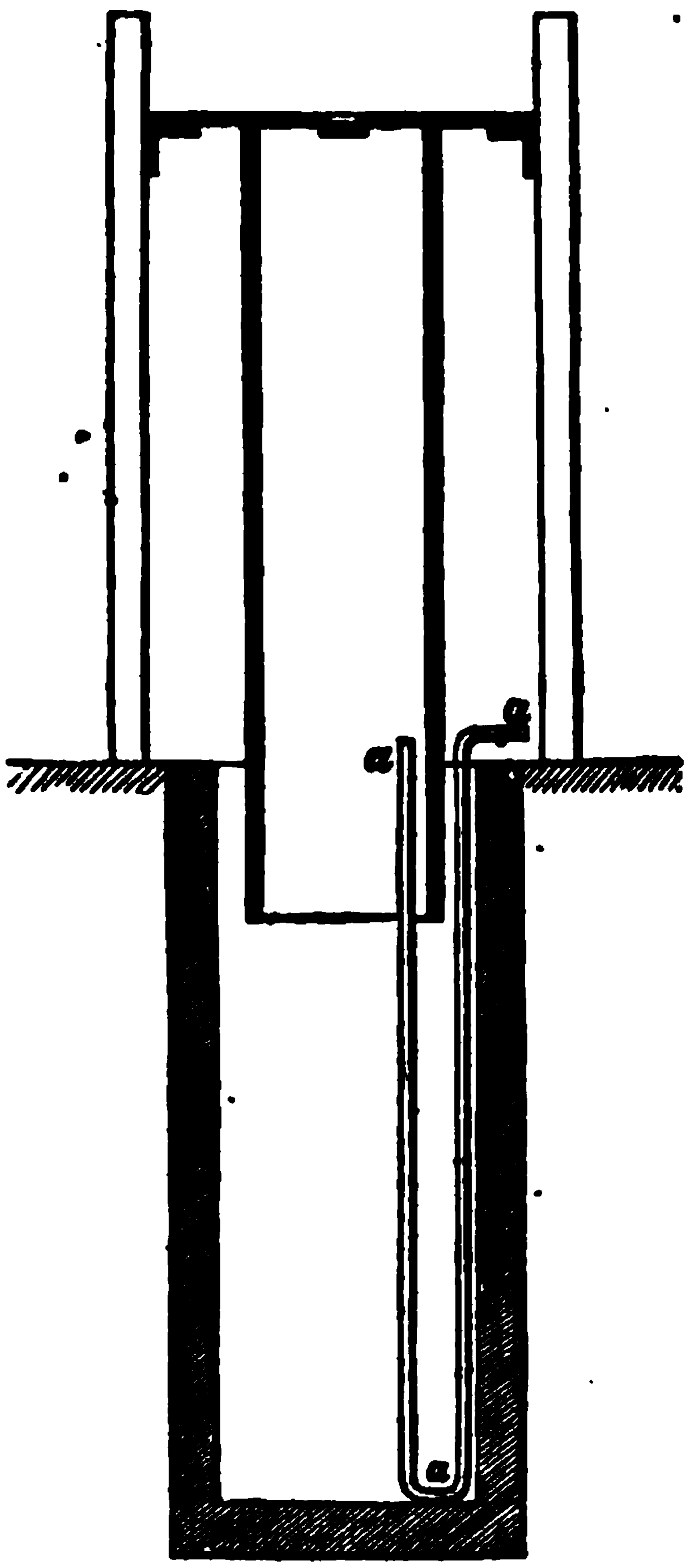
$$d' = d\sqrt{\frac{p}{f}}$$

If the pump be worked by a brake, or lever, the force upon the pump-plunger in relation to that exerted upon the end of the lever must first be calculated.

There is another method of employing water-pressure by means of an apparatus which is termed a pneumatic lift; a section of it is shown in Fig. 27. This apparatus consists of a cylinder, closed at the upper end but open at the lower, working in a well, as shown. There is a valve in the cover, the use of which we shall presently indicate. There is an air-pipe connected with an air-pump, shown at $a\,a$: when air is forced through this pipe it displaces the water from the upper part of the cylinder, momentarily causing the water on the exterior of the cylinder to stand at a higher level than that on the interior; but being at a higher level, it will exert a greater pressure on the bottom of the well, which excess of pressure being transmitted upwards within the cylinder, will be passed through the air at the top of the cylinder, causing an upward pressure on the end of the same, whereby it will be raised to any desired height. Thus the cylinder is raised by a column of water, corresponding to the depth displaced within the cylinder, the weight of such column being proportional to the pressure of the air by which it is displaced; the lifting power of this arrangement may be thus calculated:—

Let $p$ equal the pressure at which the air is forced into the

Fig. 27.




cylinder in lbs. per square inch, and $d$ the diameter of the cylinder, then the lifting force will be

$$= \cdot 7854 . p . d^2$$

The concentration of power obtained by this machine may be calculated by the formula given for the hydrostatic press, the only difference being that in the latter water is the medium through which the pressure is transmitted, whereas in the pneumatic lift the pressure is transmitted through air.

When it is required to lower the lift, after it has been raised to any required height, it is only necessary to open the valve men

tioned above, when the air will escape, and the lift will sink by its own weight.

It is evident that the same principle might be applied with any medium through which the pressure may be transmitted:

We must now proceed to speak of the action of those tools which produce impact or blows, such as the hammer, the hatchet, &c.; in this case the force applied is equivalent to the work accumulated in the tool producing the impact, such work being equal to the weight multiplied by the distance through which it passes. It is desirable here to offer a few remarks upon accumulated work. If a body whose weight is $w$, falls through a distance equal to $h$, the work done will be

$$= w\,h;$$

and the velocity which the body will have attained after falling through this distance, being equal to $v$, we shall have

$$v \text{ varies as } \sqrt{h}.$$

The reasoning from which this proportion is obtained being as follows:—

Let $t$ equal the time of fall in seconds, $g$ equal $32\frac{1}{6}$ ft., the velocity which a body will have acquired after falling the second. If a body falls freely through space, the attraction of gravitation will constantly act upon it, adding a velocity equal to $g$ every second, therefore the velocity of the body will vary as the time of falling, or

$$v \text{ varies as } t.$$

Let us now examine the relation between the time and distance fallen through. It is evident that in the first second, the body having started with no velocity, and attained at the end of the second a velocity equal 32·1695 ft., the mean velocity will be 16·0837 ft. per second, and through this space the body will fall in the first second, at the end of which time it will have acquired a velocity sufficient to carry it through 32·1695 ft. in the next second; but during that time the force of gravity continuing to act on it, it will receive the same increment of velocity as in the first second, and the total space passed through will be 48·25 ft. Following this reasoning farther, we arrive at results embodied in the following formulæ:—

$$h = \frac{1}{2}\,gt^2 = \frac{1}{2}\,tv = \frac{v^2}{2g}$$

$$v = gt = \frac{2h}{t} = \sqrt{2gh}$$

$$t = \frac{v}{g} = \frac{2h}{v} = \sqrt{\frac{2h}{g}}$$

$$g = \frac{v}{t} = \frac{v^2}{2h} = \frac{2h}{t^2}$$

By substituting other values for $g$, these equations will hold good for other forces. If a body having the weight $w$ falls through a height $h$, then will the work done

$$= wh,$$

as stated above, which by transformation becomes

$$wh = w\,\frac{gt^2}{2} = \frac{wg}{2}\,\frac{v^2}{g^2} = \frac{1}{2}\,\frac{w}{g}\,v^2$$

but $\frac{w}{g}$ is called the mass of the body, for as the mass multiplied by the attraction of gravitation is the weight, we have called $m$ the mass.

$$m.g = w$$

$$\therefore m = \frac{w}{g}$$

hence substituting in the above equation, we have

$$wh = \frac{mv^2}{2}$$

This then represents the amount of work done by any given body in falling through a given space, and if it is unopposed in its passage, this work will constantly accumulate, being at any instant equal to the mass of the body multiplied by half the square of the velocity, and this is called accumulated work. If the body meet with any resistance, the work accumulated will be expended in overcoming that resistance, or in partially overcoming it, the moving body being, in the latter case, in a state of rest.

It is work of this kind, viz., accumulated work, which is expended when a blow is struck by a hammer, and it matters not whether the hammer falls by its own weight, or is impelled by any

other force, the amount of accumulated work may be found whenever the ultimate velocity is found.

Let us work out an example by the above formula: let a body weighing 64·339 lbs. be falling with a velocity of 20 feet per second, it is required to find the accumulated work at this velocity. The mass of the body will be,

$$\frac{w}{g} = \frac{64{\cdot}339}{32{\cdot}1695} = 2;$$

hence the amount of work accumulated in the body will be

$$\frac{m\,v^2}{2} = 400 \text{ ft.-lbs.}$$

We will also calculate by the height which a body must fall through to acquire the velocity. It will be

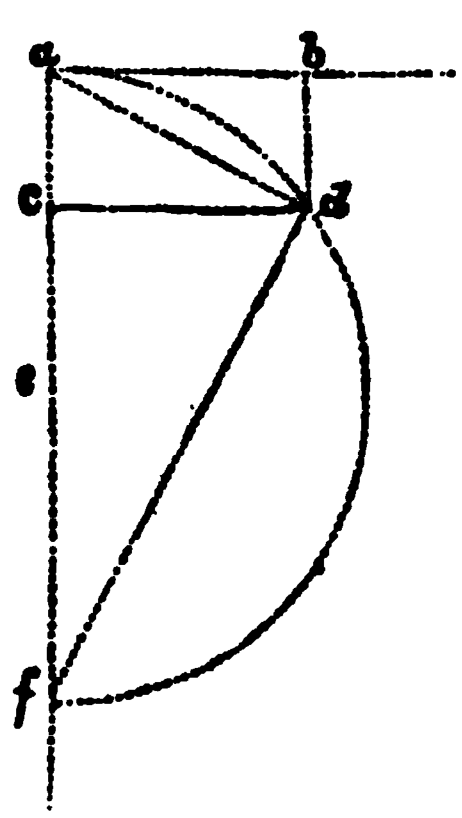
$$h = \tfrac{1}{2} \cdot \frac{v^2}{g} = \frac{400}{64{\cdot}339}$$

and the accumulated work will be

$$= w\,h = \frac{400}{64{\cdot}339}\; 64{\cdot}339 = 400 \text{ ft.-lbs.}$$

We will now pass on to consider the phenomena attendant upon rotatory motion. Let us suppose a body to be set in motion in the direction $a\,b$, Fig. 28; it is evident that in the absence of any other force, the body will move in the same direction continually; but it is possible to produce a curved motion by causing another force to act upon the body, this force acting in some other direction than $a\,b$. Let the body be attached to one end of a string $a\,e$, then will it be compelled to describe a circular arc about the point $e$; let us suppose that its velocity is such that it will pass from $a$ to $d$ in one second, then we may call the chord $a\,d$ the velocity of the body, as when the arc is small, it will very nearly coincide with its chord. By referring to the diagram, it is evident that the string, by virtue of its tensile resistance, will in one second have drawn the body through the distance $b\,d$.

Fig. 28.




Let us now find the value of $b\,d$; it is equal to $a\,c$, $a\,b$, $c\,d$, being a rectangle.

Produce the radius $a\,e$ to meet the circumference of the circle in $f$, and join $f\,d$, then, because the angle $a\,d\,f$, is inscribed in a semicircle, therefore it is a right angle, and the angle $d\,a\,f$ is common to the two triangles $a\,c\,d$, $a\,f\,d$; hence, these triangles are similar, the angle $a\,c\,d$ being a right angle, because $c\,d$ is parallel to $a\,b$, a tangent to the circle at the point where it is met by $f\,a$; therefore:

$$\frac{a\,c}{a\,d} = \frac{a\,d}{a\,f}$$

but $ad = v =$ velocity of body in ft. per second, and $a\,f = 2 =$ diameter of circle; therefore

$$\frac{ac}{v} = \frac{v}{2r}$$

$$ac = \frac{v^2}{d}$$

We must now, from this expression, find the value of the centrifugal force by proportion.

The weight of a body is the force tending to impart motion towards the centre of the earth, centrifugal force is the reaction of a body compelled to gyrate about a centre, tending to force it away from that centre; the measure of the first force, that of gravity, is $\frac{1}{2}\,g$; the measure of the second force is $\frac{v^2}{g}$. Let $c$ represent centrifugal force, that is to say the tension of the string $a\,e$, which holds in the gyrating body as a table supports a body tending to fall, the string resisting the *weight* of centrifugal force, and the table resisting the *weight* of gravitating force; hence the following proportion holds good.

$$\tfrac{1}{2}g \ : \ \frac{v^2}{2v} \ :: \ w \ : \ c$$

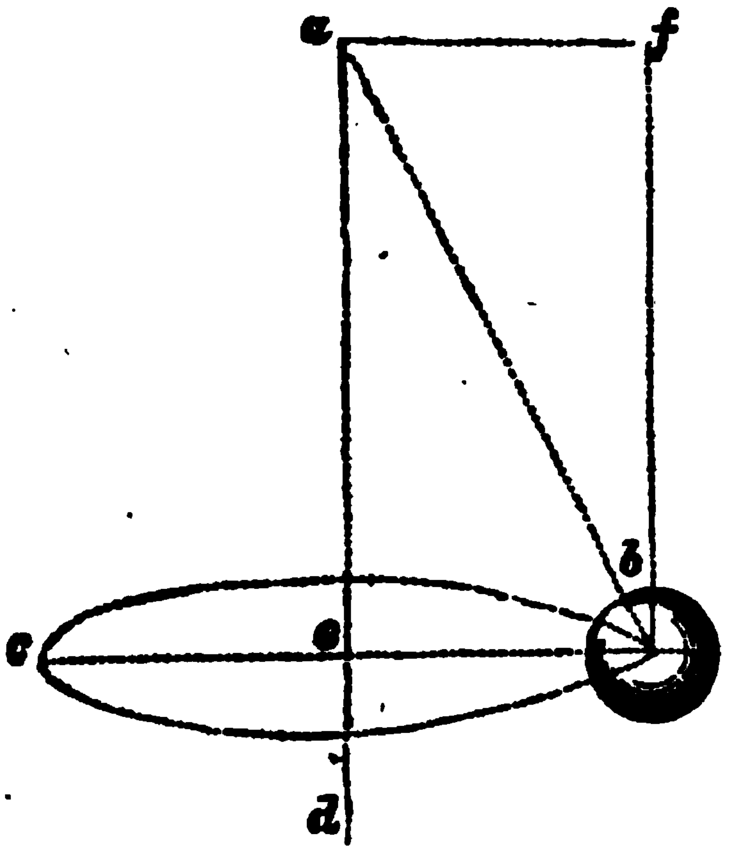
$$\therefore c = \frac{wv^2}{rg}$$

From this equation, the centrifugal force may in any case be obtained when the body revolves in a circle, or in any other curve if its radius or curvature, at the instant when the velocity is given, be known. The method of finding the radius of the circle osculating any given mathematical curve, will be found in treatises devoted to that subject, and as the case seldom applies to

the machinery we shall hereafter consider, we shall not further dilate upon it.

It is necessary now to examine the principle upon which the conical pendulum is constructed. Let *a b*, Fig. 29, represent a wire or string fixed by a pin at *a*, and carrying a heavy ball at *b*; let this ball *b* be revolving in an orbit, such as that shown by the dotted circle *b c*. From *a* let fall a perpendicular to the horizon, as shown at *a d*, the perpendicular passing through the centre of the circle *b c*, and forming the axis of the imaginary cone *a b c*, described by the revolution of the arm *a b*. From the centre of the ball *b*, let fall *b e* perpendicular to *a d*, complete the parallelogram *a e*, *b f*, we shall then have two forces acting on the ball *b*, tending to move it about *a* as the centre. The weight being *w*, it will produce a force whose moment about *a*

Fig. 29.




$$= w \times e b.$$

In the other direction, we have, if *c* equals the centrifugal force of the ball, a force whose moment is

$$= c \times e a.$$

If the ball is in equilibrium these two forces must balance, and therefore,

$$c \times e a = w \times e b.$$

Let $h = e a$ the height of the point of suspension above the plane of gyration. Let $r =$ the radius of gyration *e b*, then will

$$c = \frac{w v^2}{r g}$$

$$\text{but } v = 3{\cdot}1416\, r \times 2n$$

where $n =$ the number of revolutions per second; but if $n =$ the number of revolutions per minute,

$$v^2 = \left\{ \frac{3{\cdot}1416 \cdot r \times 2n}{60} \right\}^2$$

By replacing

$$h = \frac{g r^2}{v^2} = \frac{35225 \text{ inches}}{n^2}$$

nearly. This formula may also be written by an obvious transformation

$$h = \left\{ \frac{187.7}{n} \right\}^2$$

and from this we derive

$$n = \frac{187{\cdot}7}{\sqrt{h}}$$

Another class of rotatory motion with which we shall subsequently meet, consists in the movement of a fly-wheel employed to prevent any great variation of velocity, which might occur by reason of the varying force exerted upon the shaft of the machine to which it is applied. The theory of the fly-wheel is somewhat complicated, and therefore unfit for insertion in the present treatise. In many instances rules have been given of a simple character, but incorrect, and therefore useless.

We will now conclude this account of statics and dynamics, which will be found sufficient for our subsequent requirements.

## CHAPTER IX.

### ON THE GENERAL ARRANGEMENT OF THE STEAM-ENGINE.

LET us now examine the means necessary to be taken in order to convert the heat contained by the steam, with which the steam-engine is supplied, into dynamic force, in a form suitable to our requirements.

There are three kinds of engines, which must be considered separately: in the first class the piston admits only of rectilineal motion; while in the second class the piston revolves, either continuously or with a reciprocating motion, about an axis or centre; and in the third class the piston moves in such a manner that its periphery describes a zone of a sphere. In engines of the first class the piston is impelled alternately in each direction by the difference between the pressures existing on the opposite sides of the same; thus in a condensing engine, if $p$ represent the pressure of steam, and $P$ the vacuum, both being stated in pounds per square inch, then, taking 14·7 lbs. per square inch as the mean pressure of the atmosphere, we shall have for the effective force $f$ per square inch on the steam-side of the piston—

$$\begin{aligned} f &= p + 14\cdot7 - \left\{ 14\cdot7 - P \right\} \\ &= p + P. \end{aligned}$$

Let, for example, $p = 20$ lbs. per square inch, and $P = 11$ lbs. per square inch, then will the effective pressure per square inch be,

$$f = 20 + 11 = 31 \text{ lbs. per square inch.}$$

In a non-condensing engine the vacuum becomes nothing, hence in that case the steam-pressure is the effective pressure. The power of any engine is very easily calculated,—it is represented by the amount of work done in a given time, and is usually referred to the power of a horse, which was determined by Watt to be

$$= 33{,}000 \text{ ft.-lbs. per minute.}$$

Hence the power of any given engine will be as follows: Let $p =$

effective pressure of steam, $a$ = area of piston in inches, $d$ = diameter of piston, $v$ = space passed through by piston in feet, $t$ = time occupied by the piston in passing through the space $v$ in minutes; $H\,P$ = equal horse-power, $l$ = length of crank, $n$ = number of revolutions performed while the piston passes through the space $v$; then

$$H\,P = \frac{p\,.\,a\,.\,v}{33000\,.\,t}$$

but

$$a = 0{\cdot}7854d^2$$
$$v = 4\,.\,n\,.\,l$$

therefore

$$H\,P - \frac{p.\,0{\cdot}7854\,d^2.4.\,n\,l}{33000\,t}$$

$$= \frac{p.\,d^2.\,n.\,l}{10504\,t} \text{ nearly.}$$

Let it be required to calculate the power of an engine having one cylinder 20 inches in diameter, with a crank 1 foot 6 inches in length, or 1·5 feet; let the effective pressure be 25 lbs. per square inch, and the number of revolutions of the crank thirty-five in one minute, then

$$H\,P = \frac{25 \times 400 \times 35 \times 1{\cdot}5}{10504 \times 1} = 49{\cdot}98,$$

say 50 horse-power.

There are two methods of calculating the horse-power for condensing engines, the results being called the indicated horse-power and the nominal horse-power. To calculate the latter, it will be necessary to proceed as follows:—

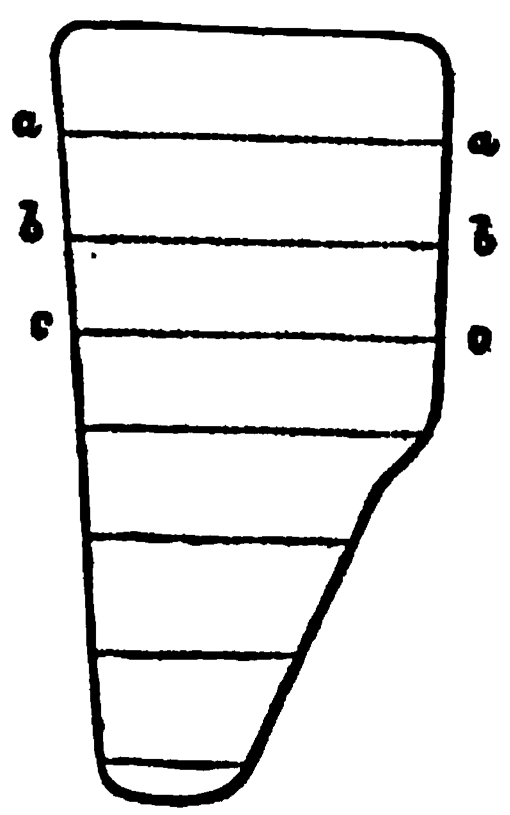
Take for the effective pressure 7 lbs. per square inch, and for the speed 220 ft. per minute; let the area of the piston be 1000 in., then, by the first rule,

$$H\,P = \frac{7 \times 1000 \times 220}{33000 \times 1} - 46{\cdot}66.$$

For the actual or indicated power, we must follow a different course, taking for effective pressure the mean effective pressure; to find which it is necessary to take a diagram from the engine, which is done thus:—A piston is accurately fitted to a small cylinder, screwed in the top or bottom of the main cylinder; the piston

is retained at mid-stroke by a spiral spring, and when pressure occurs in excess beneath the piston, the latter rises, and *vice versâ;* to the piston-rod is attached a pencil, which, as the little piston rises and falls, describes a line straight or curved, on a piece of paper, which moves backward and forward with the piston in the main steam-cylinder.

Fig. 30.




From the figure produced by the indicator the pressure of the steam in the cylinder at any point in the stroke may be found; the mean pressure may be taken with sufficient accuracy for practical purposes as follows: Draw a number of ordinates *a a*, *b b*, &c., upon the indicator card, measure the ordinates on the scale of pressures, and divide the sum of the pressures so found by the number of ordinates taken.

A rule, very frequently used for condensing marine engines, is constructed on the assumption of 7 lbs. pressure of steam per square inch, with a speed of 200 feet per minute; the formula for nominal horse-power will then become:

$$HP = \frac{p. a. v}{33000 f} = \frac{7 \times 0{\cdot}7854 d^2 \times 200.}{33000}$$

$$= \frac{d^2}{30} \text{ nearly.}$$

The former formula would be:

$$HP = \frac{d^2}{24}$$

It will immediately be seen that rules for nominal horse-power are little better than empirical, being merely useful in a commercial sense, and rather as a standard of value than power.

The following formulæ will be found sufficiently accurate for practical purposes, and useful to those who are engaged in designing steam-engines:—

$$HP = \frac{p.n.l\,d^2}{10500}$$

$$p = \frac{10500\,HP}{n.l.d^2}$$

$$n = \frac{10500\,HP}{p.l.d^2}$$

$$l = \frac{10500\,HP}{p.n.d^2}$$

$$d = \sqrt{\frac{10500\,HP}{p.n.l}}$$

We will next speak of the power of those engines which are fitted with pistons revolving about an axis or centre, first taking the case of a piston revolving continuously in one direction, the piston being rectangular. Let $r$ = the distance in inches from the centre of revolution to the nearest edge of the piston, $r'$ = the distance from the centre to the farthest edge of the same, $b$ = breadth of piston in inches, $p$ = effective pressure of steam, $n$ = number of revolutions per minute. Then—

$$HP = b\left\{ r'-r \right\} \cdot \frac{3{\cdot}1416}{12} \cdot \frac{r+r'}{2} \cdot \frac{n.p.}{33000}$$

because $b\left\{ r'-r \right\}$ = area of piston in inches,

and $\dfrac{3{\cdot}1416\left\{ r+r' \right\}}{24}$ = mean space passed through by the piston in one revolution.

By reduction:—

$$HP = \frac{n.p}{252100}\left\{ r'^2 - r^2 \right\} b$$

If the piston oscillates through a portion of the revolution, the formula must be modified thus:—

Let $\frac{1}{m}$ represent the fraction of a revolution through which the piston oscilates, then the formula will be, $n$ being equal to the number of oscillations per minute:—

$$HP - \frac{n.p}{252{,}100}\left\{ r'^2 - r^2 \right\} \frac{b}{m}$$

thus, if the piston vibrates in a semicircle—

$$HP = \frac{n.p.b}{504{,}200}\left\{ r'^2 - r^2 \right\}$$

if it vibrates in a quadrant of a circle—

$$H P = \frac{n.\ p.\ b.}{1,008,400} \left\{ r'^2 . r^2 \right\}$$

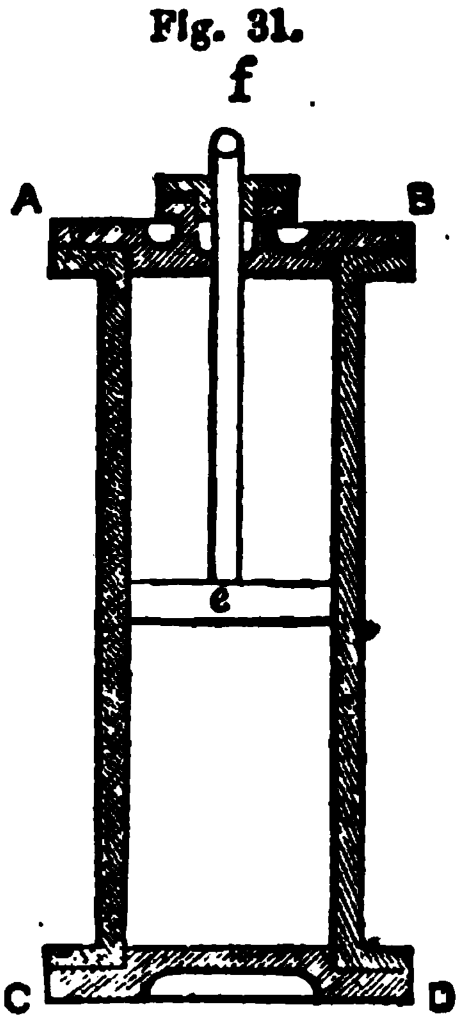
We now have to consider the last kind of engine of which we spoke, viz., that in which the circumference of the piston describes a zone of a sphere; this is called the disc engine. The disc or piston is placed between two cones, united by the spherical zone described by the periphery of the piston, which in its motion reminds us of a disc, which having been caused to spin upon its edge is about to fall, when it performs gyrations about its rim; we shall in the present place insert an approximate rule whereby its power may be calculated. Let $r$ = radius of the disc or piston, $r'$ = radius of sphere upon which as a centre the disc gyrates, $t$ = thickness of the edge of the spherical zone, or length of the steam-chamber, all in inches, then—

$$H P = \frac{3{\cdot}1416\ tn.\ p}{2 \times 3 \times 12 \times 33000 \times r} \left\{ r^3 . r'^3 \right\}$$

$$= \frac{t.\ n.\ p}{756,310r} \left\{ r^3 . r'^3 \right\}$$

We have now considered the arrangement of the steam-engine with regard to power, our next step will consist in examining the means of applying such power.

Fig. 31.

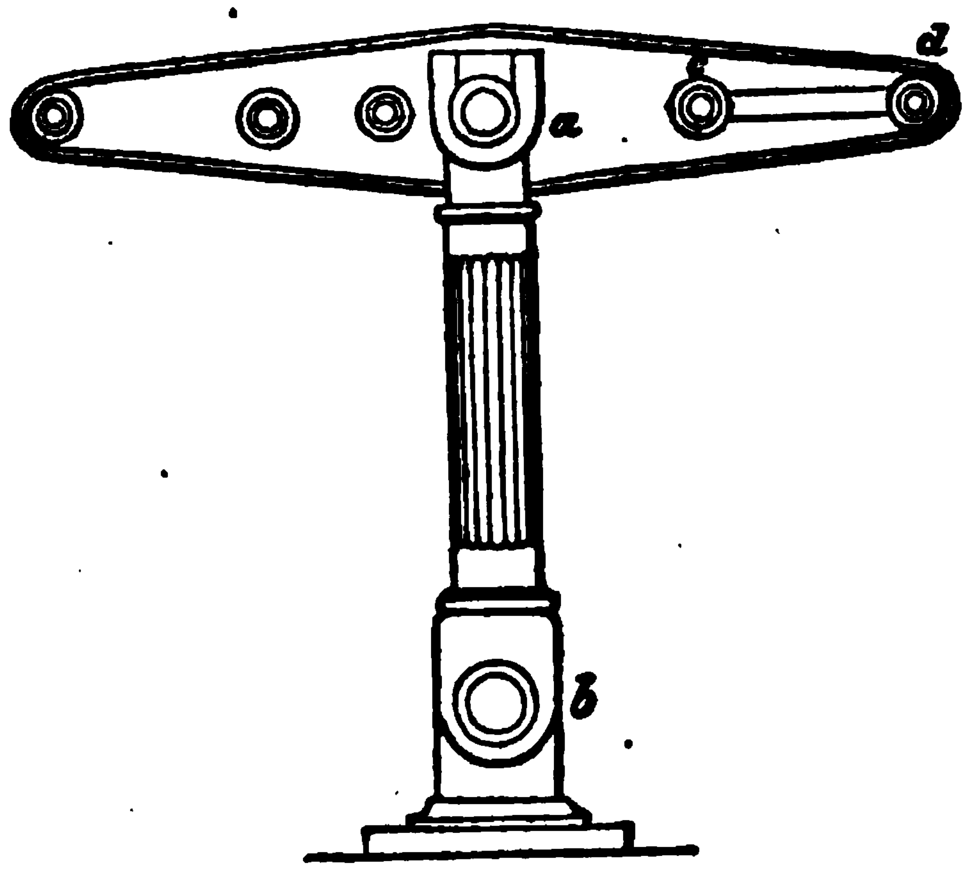



Let us commence with the first class of steam-engines. Here we have the work presented in the form of a pressure acting in a straight line, alternately in opposite directions. The piston is urged backwards and forwards from end to end of the cylinder by the steam pressure acting alternately upon each side of it. To this piston is attached a rod, which passing out at an air-tight aperture in the cover of the cylinder, communicates the motion of the piston from within the cylinder to the external machinery; this arrangement is shown in Fig. 31, in which A B C D is the steam-cylinder, $e$ the piston, and $e f$ the piston-rod. In the first case, let the point of application of the power be required to move in a straight line, then the piston-rod

may act directly upon the work, or it may operate through the intervention of a beam; but if this latter arrangement is employed, some means must be taken to enable the head of the piston rod to move in a straight line, notwithstanding the curvilinear motion of the end of the beam or lever, for if this were neglected the piston rod would be bent. The means of effecting the desired end are very numerous, but we shall here describe only those which have been found practically useful.

The simplest method consists of so forming the column *a b*, Fig. 32, which supports the bearings upon which the main beam

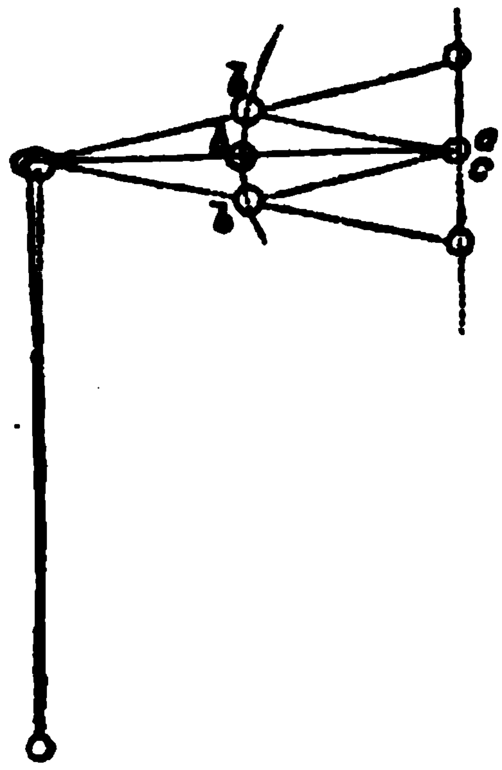
Fig. 32.




*d*, oscillates, that it may vibrate upon an axis placed at *b*, the lower extremity, whereby that end of the beam to which the piston rod is attached, is enabled to adjust itself. The extremity of the beam is caused to move in a line very nearly straight by means of the link, *c d*, which is attached to the beam at *c* by a centre, and to a part of the framing at *d*, in the same vertical plane with the piston rod. The manner in which this contrivance effects the desired end is sufficiently simple, as may be shown by the diagram, Fig. 33. Let the full lines represent the bars, constituting the parallel motion, as it is called, at mid-stroke, when they will be parallel to each other; then the dotted lines will represent their position after the stroke has been continued through a short distance, during which the deviation of the piston-rod head from a rectilineal movement, would be equal to the versine of

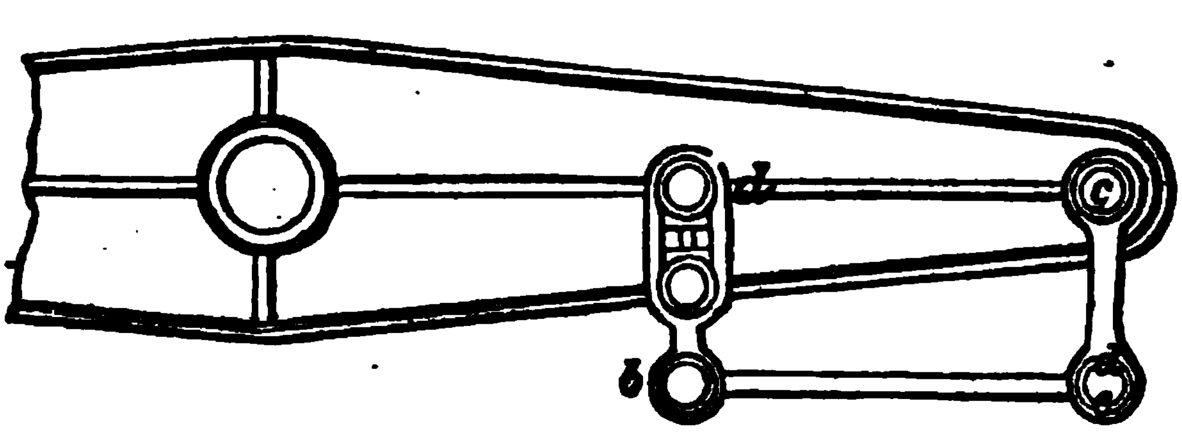
the angle passed through by the bar *a b*, multiplied by the length of the bar, had the centre *b* been fixed; as it is, however, the centre *b* is carried at the extremity of the bar *b c*, which moves upon a fixed centre at *c*, and the deviation of the point *b* from rectilineal motion being in a contrary direction to the deviation mentioned above, compensates for it; by this contrivance it is not an absolutely straight motion that is obtained, but one very nearly approximating to it.

Fig. 33.




Under some circumstances it would, however, be unsatisfactory to use the above movement, which is most frequently applied to half-beam or grasshopper engines. As the vibration of so large a mass of the beam and the pillar supporting it, would in a machine of considerable dimensions give rise to serious inconvenience, an arrangement shown, Fig. 34, is, under these circumstances employed, and combines within itself the properties of two parallel motions, the first, which in its action is identical to that described above, corrects the deviation of the top of the piston rod; it is formed by the bars *a b*, *b c*, which are attached by parallel links to the main beam, as shown; at the centre, or near it, of the vertical link, *b d*, there also exists a point whose motion approximates nearly to a rectilineal movement; and the means

Fig. 34.

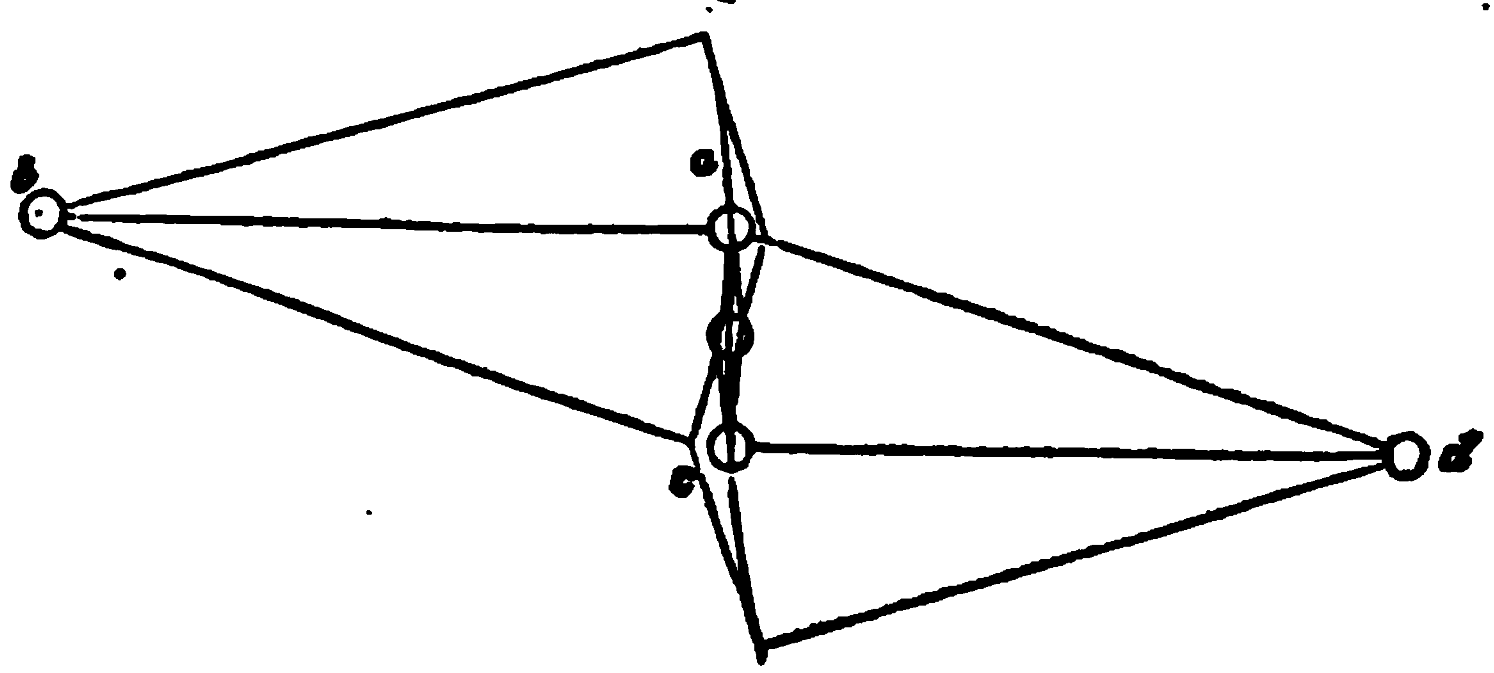



by which this is obtained we will describe by the assistance of another diagram, Fig. 35.

*a b* is one-half of the main beam, working upon a fixed centre at *b*; *c d* is a link of equal length working upon a fixed centre at

*d*; the extremities of the two bars are connected by the link *a c*, the whole being so adjusted that at mid-stroke the angles *a b c*, *d a c*, are right angles; then by the oscillation of the arms *a b*

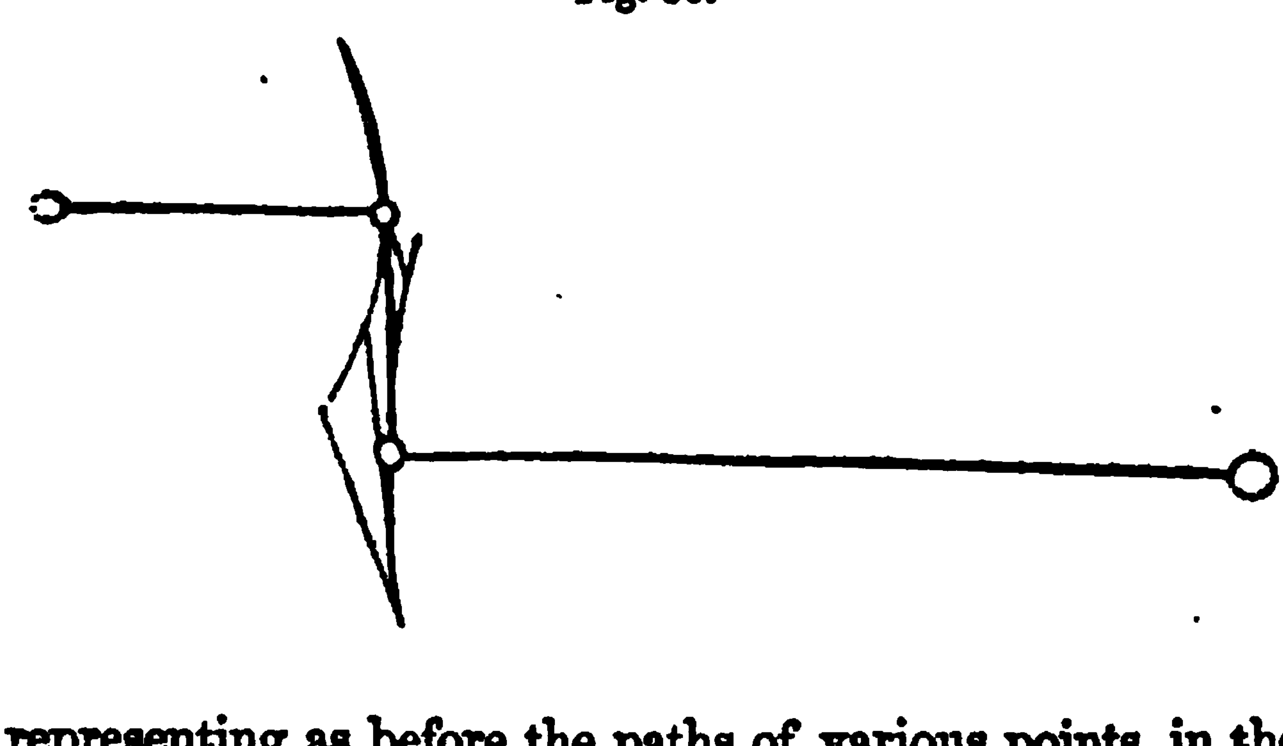
Fig. 35.




and *c d* the extremities of the link *a c* are caused to deviate in opposite directions. The dotted lines show the paths of various points in the link *a c*, which, it will be observed, approximate more nearly to a straight line as we approach the centre of the link.

If in the case of the motion last described the arms be not of equal length, then it is evident that that point of the link, *a c*, which moves in a line most nearly approximating to a straight line will not be in the centre of the link, but nearer the longest arm. A motion with unequal arms is shown, Fig. 36, the dotted

Fig. 36.

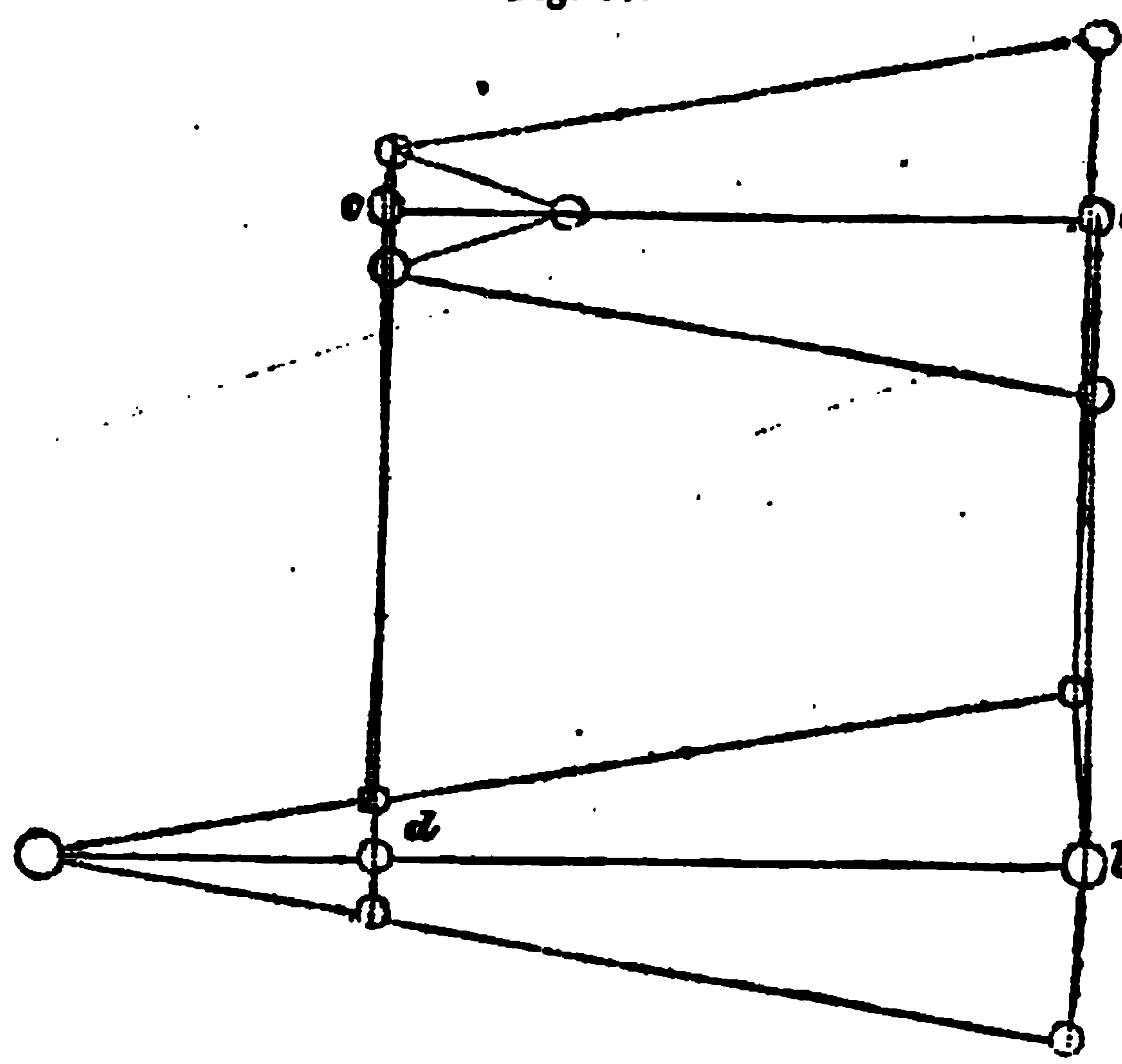


lines representing as before the paths of various points in the connecting link.

In marine engines an arrangement differing in form must be

employed to attain the same end. A common form is shown in Fig. 37; *a* is the head of the piston rod to which a cross-head is attached; from this cross-head arms, *a b*, run down to the beam

Fig. 37.




which is placed beneath, and arms, *a c*, run from the cross-head to a short arm, capable of moving upon a centre. Upon the same centre is fixed another arm, or the same may in some cases be used, from the extremities of which rods pass down to the beams beneath. The length of the short arms is adjusted in right proportion to correct the deviation, which might otherwise be caused by the angular motion of the beams. Another means of regulating the motion of the piston rod consists in attaching to its upper extremity a cross-head, carrying blocks, which move between guides fixed parallel to the axis of the piston rod. Other kinds of motions are also occasionally used, but they are principally derived from the foregoing, wherefore it is unnecessary to give a complete account of these movements.

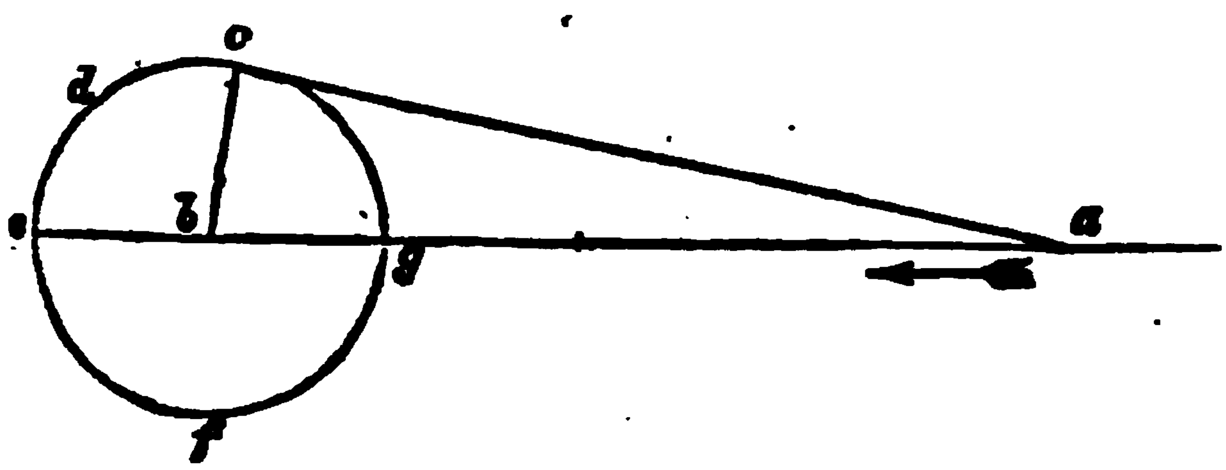
If it be necessary that the rod attached to the other extremity of the beam should move rectilineally, then the same means may be employed to insure rectilineal motion as were used to regulate the motion of the piston rod.

It most frequently happens that the motion of machinery to be driven by steam-power is rotatory, when it will be necessary to adopt

some contrivance for converting the reciprocating rectilineal motion of the piston into a rotatory motion. In order to effect this end, numerous arrangements have been devised, but none of them answer so well the purpose as does the crank, nor is any other form practically applied; we shall therefore describe only the means furnished by this contrivance, which deserves a very careful consideration.

Let $a$, Fig. 38, represent the head of the piston rod, which is

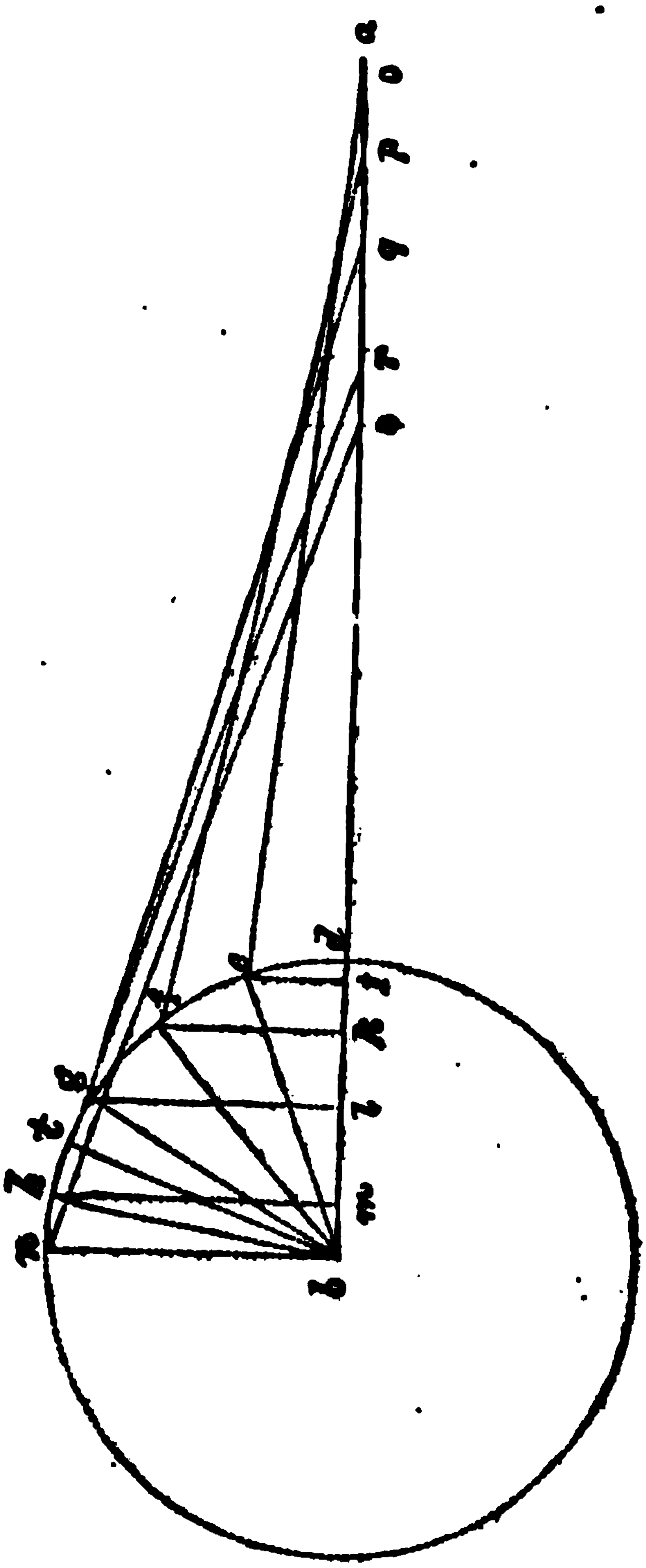
Fig. 38.




guided so that it can only move in the direction of the straight line $a\ b$. Let $b\ c$ be a crank capable of revolving about the point $b$ as a centre, the extremity $c$ describing the dotted circle. The extremity of the piston rod is connected with the extremity $c$ of the crank by means of a connecting rod, $a\ c$, the points of junction, $a$ and $c$, being made by pins, about which the connecting rod may move without restraint. If the point $a$ be supposed to move forward in the direction of the arrow, the extremity $c$ of the crank will describe an arc from $c$ towards $d$, until it arrives at the point $e$, which is in the straight line with $a\ b$. Then it is evident that whichever direction the point $a$ tends to move in, no motion can possibly be produced in $c$, as the force would act exactly at right angles to the direction in which the point $c$ must be moved. If $c$ be carried past this point, and a motion the reverse of the former be imparted to $a$, the extremity $c$ of the crank will pass through the semi-circumference $e\ f\ g$, and upon arriving at the point $g$ we shall find that this, like the point $e$, is a point of no motion. The means employed in practice to carry the crank past these points of no motion, technically called dead points, will be explained hereafter, our attention being at present confined to the action of the crank in regard to the alteration suffered by the force in its transmission through the same.

To illustrate the action of the crank another diagram will be serviceable. It is shown at figure 39: *a* is the head of the piston rod, *b* the centre upon which the crank revolves, and *c d* the dead points; *a d* is the connecting rod; the position is shown by the full

Fig. 39.



lines when the crank is upon the dead point *d*. The dotted circle which represents the path of the extremity *d* of the crank *b d* is divided into eighteen parts in order that the variation of the force transmitted to the shaft, upon which the crank is fixed, at different

parts of the stroke, may be examined. It will be sufficient for the present purpose to investigate the case for the points $e\ f\ g\ h$ in the first quadrant of the circle; but it is desirable to include an extra point, $n\ b$, showing the position of the crank when at right angles to the straight line $a\ c$. In order to comprehend the variations undergone by the motive force applied at the point $e$, the case must be treated by the well known principle of the parallelogram of forces.

The length of the connecting rod being constant, we can find the position of the head of the piston rod corresponding to each of the points $e\ f\ g$, &c., by marking off from those points upon the line $a\ c$, distances $e\ o\ f\ p$, &c., each equal to the length of the connecting rod.

The first step will consist in the resolution of the strain in the direction of the connecting rod, and in the other direction in which it acts, of which, however, no mention has yet been made. The directions in which the force will be resolved are evidently the axis of the piston rod, and at right angles to the same, the latter producing pressure upon the guide-blocks and guides. Hence it may be concluded that in the case of any position, such, for instance, as that corresponding with the point $g$, the relative values of the forces will be represented by the sides of a right angle triangle, consisting of the length and position of the connecting rod $g\ q$, the perpendicular let fall from the point $g$ upon $a\ c$, this perpendicular being in the present case $g\ l$, and that part of the line $a\ c$ which is contained between the extremity of the connecting rod and the perpendicular mentioned above, in the present case $l\ q$.

Let P represent the total pressure on the piston, and therefore the total pressure acting in the direction $a\ c$; then the forces acting in the various directions will be as follows. The pressure on the guide-blocks will be

$$= P\,\frac{l\,g}{l\,q}.$$

That on the connecting rod will be

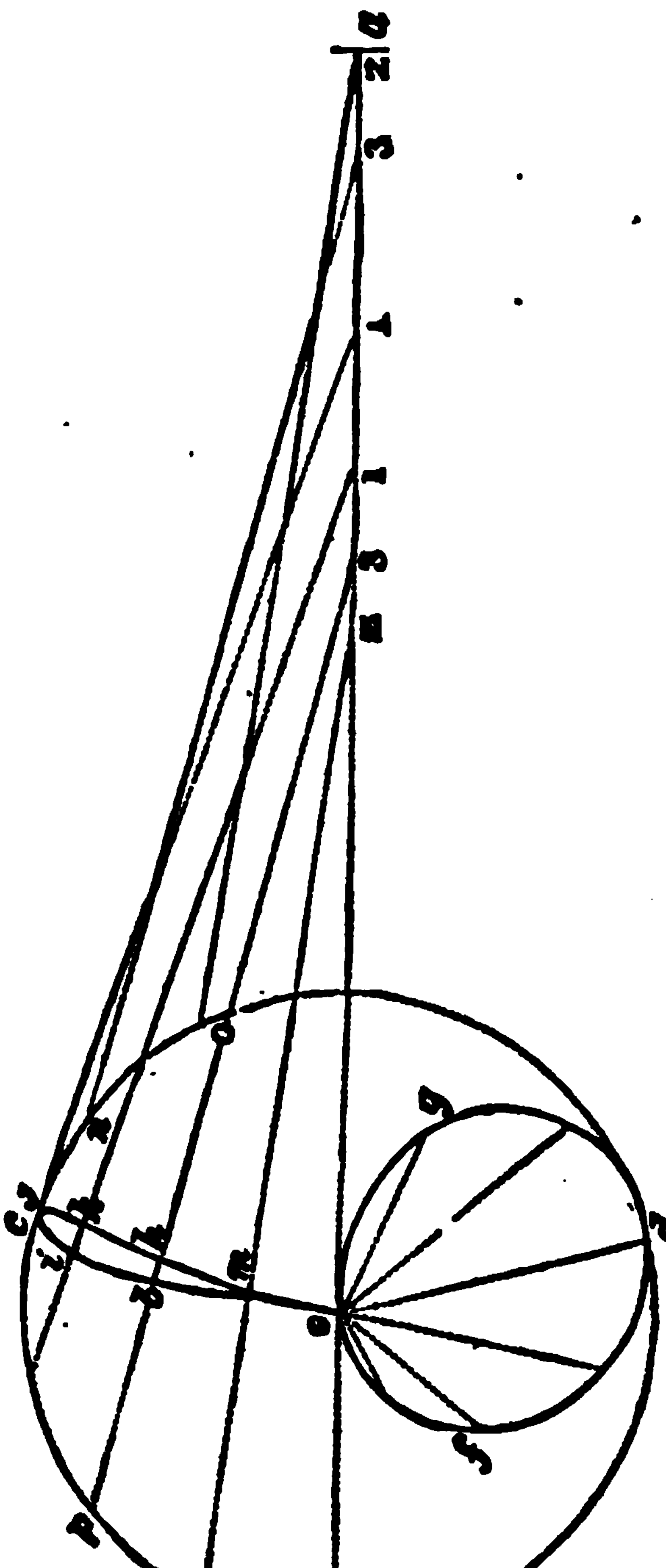
$$= P\,\frac{q\,g}{l\,q}.$$

but $q\ g$ is constant; call it $=$ L, then the force upon the connecting-rod

$$= P \frac{L}{lq}$$

In order to find the moment of the last force, about the centre $b$ produce the line $q\ g$, and from the point $b$ let fall upon it the per-

Fig. 40.

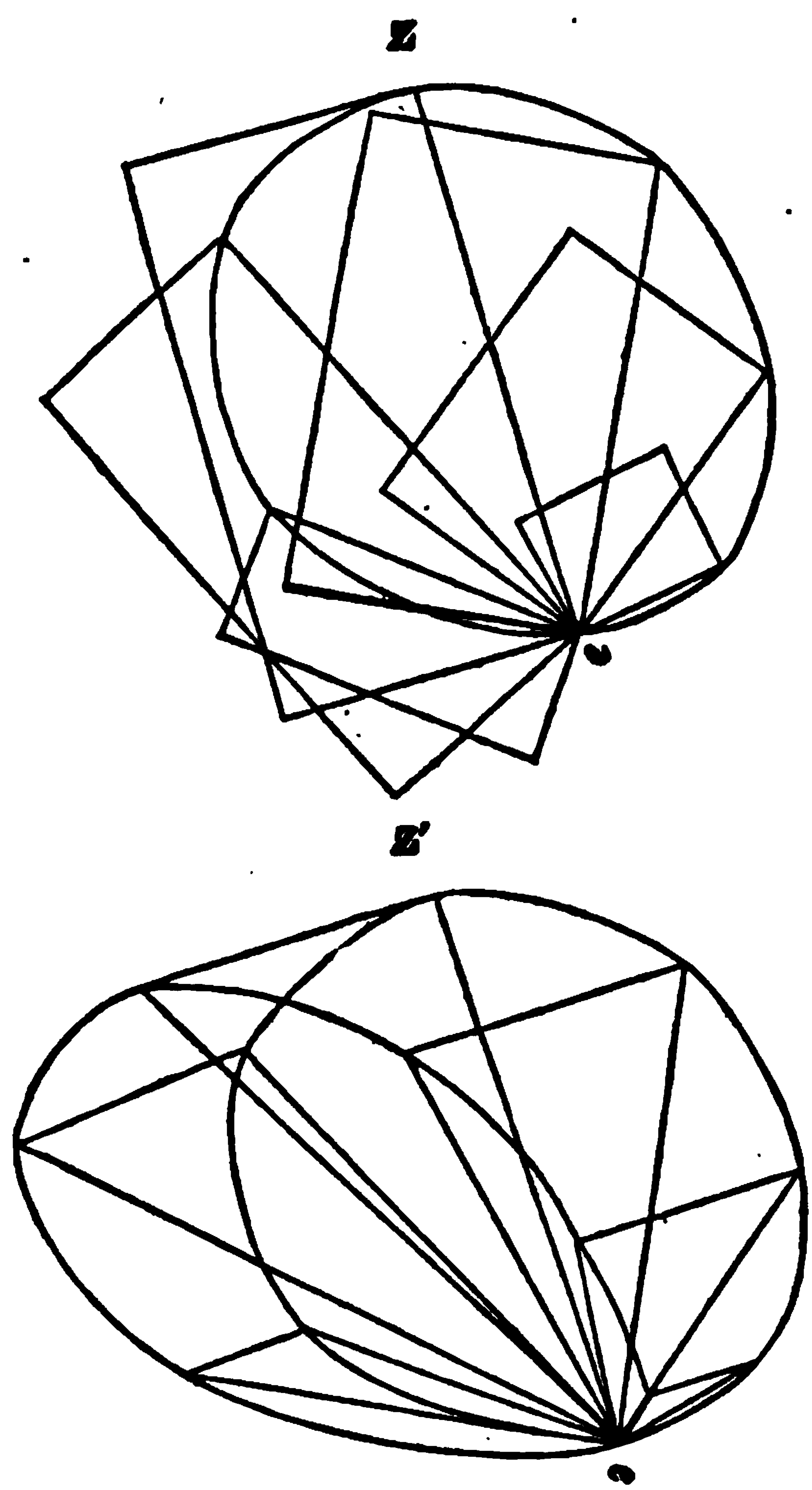


pendicular $b\ t$, then will $b\ t$ represent the distance at which the force acts, and the moment about $b$ will be

$$= P \frac{L}{lb} bt$$

In a similar manner the moment of power may be found for the other points. The lower quadrant immediately beneath *b n d* will exhibit the same phases, the remaining quadrants being different. Having found a means of calculating the moment of pressure, it

Fig. 40 (*a*).



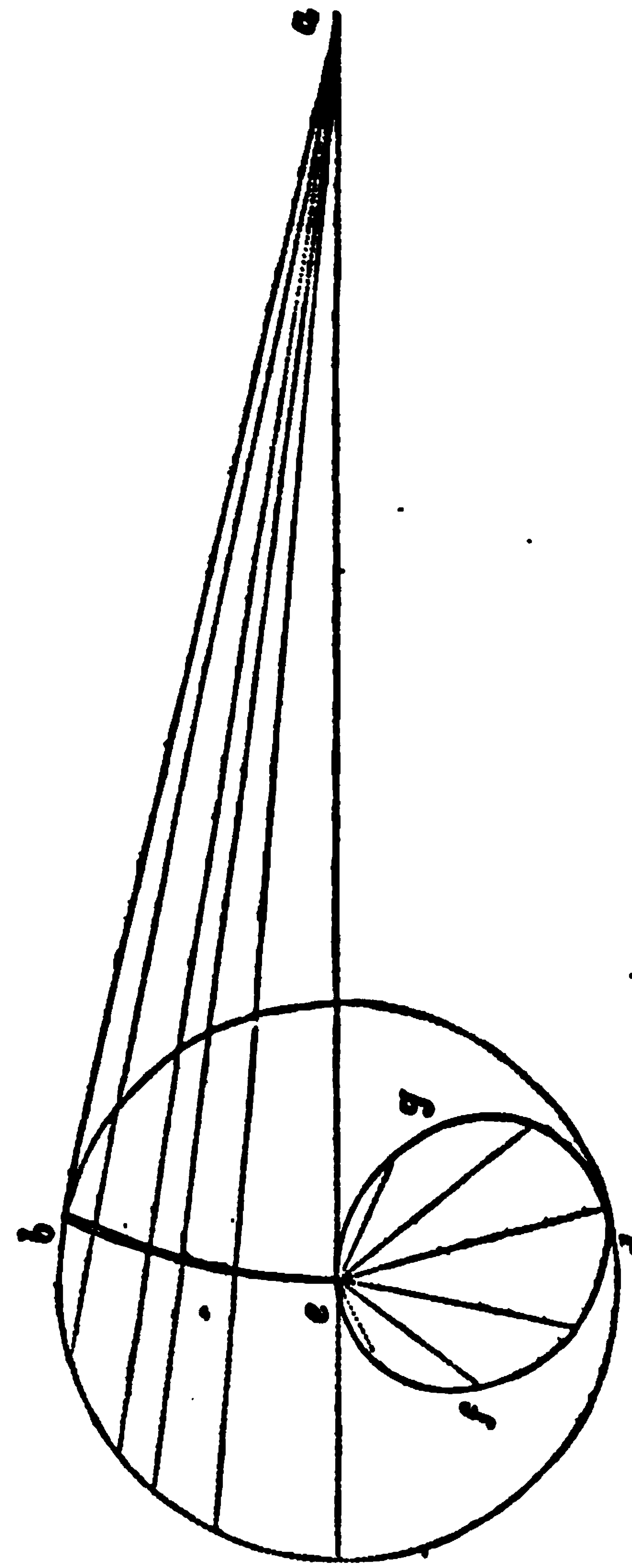

may be interesting to draw the curve through which the point *t* passes.

Let *a b*, Fig. 40, be the straight line in which the head of the piston rod moves. The change of force due to the position of the

crank shall first be determined, the force on the connecting rod being for the present supposed to be constant; then the point upon which the perpendicular to the connecting-rod falls will at each point of intersection, there being fourteen intersections, pass through the points *l i j k h m* and *e*; and if the lengths of these perpendiculars be laid off radially from the centre *e* along the axis of the crank for each position, we shall obtain the figure *e f g d*. The force on the connecting rod is not, however, constant, but varies as the length of the perpendicular, divided by the horizontal distance between the extremities of the connecting rod. It is worthy of note that at symmetrical divisions, as *oo pp*, the positions of the connecting rod are parallel, and therefore the strain upon the connecting rod at any point at a given distance from the axis of one side of a line at right angles to the same is equal to the strain upon it for a corresponding point on the other side of the said line. We may find the relative value of the moment actually acting upon the centre *e*, when the pressure in the direction *a b* is constant, for any position of the crank, by multiplying the length of the perpendicular by the relative pressure on the connecting rod, the result being represented geometrically by an area or surface, which may be either a rectangle or a right-angled triangle. At Z is shown an enlarged view of the figure *e f g d*, the moments being represented by rectangles. It is evident that if triangles be taken instead of rectangles, these triangles being placed with their apices meeting at the centre *e*, the total sum for every position of the crank in the semicircle may be conceived to constitute a solid, bounded by three surfaces, of which two are plain and one curved. such a solid is shown at *Z′*; then if any section of this solid be taken by a plane passing through the point *e*, the plane being perpendicular to the upper surface, we shall obtain a triangle representing the relative moment, about *e*, when the crank axis lies in that plane. It may be desirable to notice the effect of lengthening or shortening the connecting rod. If a longer connecting rod be used the perpendiculars for all positions on the nearest semicircle to the head of the piston-rod will be shortened, and those on the opposite semicircle will be lengthened, the result of which will be that the figure *e f g d* will more nearly approach a symmetrical form, approaching nearer in contour to the dotted circle shown as the length of the connecting rod increases. Hence, the longer the

connecting rod, the more uniformly will the engine work; and the shorter the connecting rod, the more irregular will its movements be. It is evident that the figure *e f g d* can never become

Fig. 41.




perfectly symmetrical, as in that case the connecting rod would be required to be infinitely long.

Before taking leave of the crank, it is desirable to mention the

action of the crank under the oscillating engine. In this case, the cylinder is placed upon trunnions, the piston-rod head being jointed to the crank, the lateral movement of which is allowed for by the vibration of the cylinder. The pressure upon the crank, coming always direct from the piston, is uniform, hence the variations of the length of the perpendiculars only need be considered. In Fig. 41 we show curves illustrating this variation. The point *a* is the axis upon which the cylinder oscillates; *b e* is the curve described by the point upon which the perpendiculars fall for each position of the crank, and *e f d g* exhibits the variation of the ultimate moment of power about the centre *e* for one stroke. It is evident from these diagrams that the action of the oscillating engine is far more uniform than that of the fixed cylinder engine, as the solid, illustrative of the action of the crank in the former machine, will be of uniform thickness throughout.

When a beam engine is used to give a rotatory motion, the connecting rod is attached to one end of the beam.

The pumps consist of cylinders, fitted with plungers, and their action will hereafter be described.

The slides by which the steam is admitted to the cylinder have a rectilineal movement, derived from the motion of the engine itself. In engines having rotatory motion, this rectilineal movement is obtained by means of an eccentric wheel fixed upon the main shaft, as shown, Fig. 42; its action is equivalent to that of

Fig. 42.

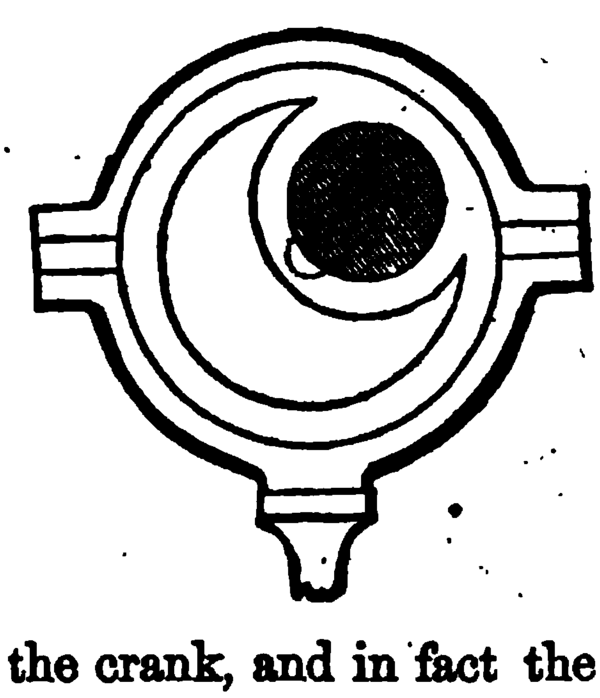
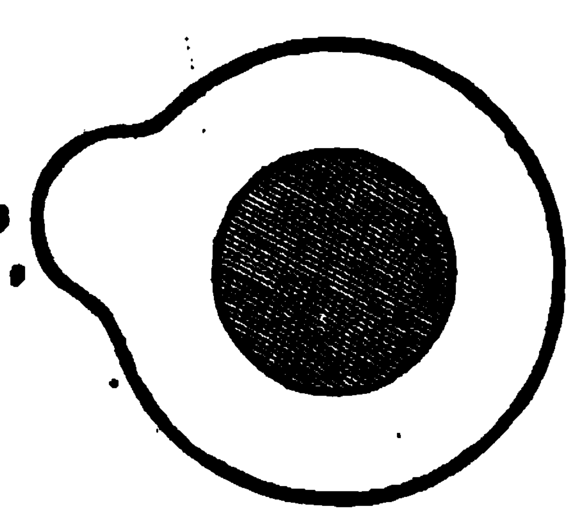


Fig. 43.



the crank, and in fact the eccentric might be replaced by a crank, as shown by the dotted lines.

When an intermittent motion is required, a contrivance called a cam is made use of, which cam is of the form shown in Fig. 43.

The camber *a* raises the end of the lever at every revolution, the end falling again as soon as the camber has passed it.

With regard to the rotatory engine there is little to be said, as the rotatory motion is immediately obtained. In the disc engine a piston rod attached to the centre of the piston describes a cone, and its extremity, which describes a circle, is fitted to a crank. The last part of the steam-engine which will be mentioned here is common to all varieties of land engines; it is the fly-wheel, which consists of a heavy wheel placed on the main shaft, to carry the crank over the dead points, and to act as a corrective to the variation of force on the shaft. Its action is this: at the point of maximum speed an extra quantity of work is accumulated in the fly-wheel, which is expended during the period of minimum force.

## CHAPTER X.

### GENERAL PRINCIPLES OF STEAM-BOILERS.

THE vessels in which water is evaporated in order to supply steam to steam-engines, are technically called boilers, and their forms are very varied. The first point to be considered is the power of a boiler: that is to say, to determine the quantity of water which the boiler will evaporate, the horse-power being considered equivalent to the evaporation of one cubic foot of water per hour. The quantity of fire and heating surface requisite to evaporate one cubic foot of water per hour, has at various times been determined. It was formerly taken at one square foot of fire surface, and nine horizontal feet, or one yard horizontal heating surface, sometimes also called water surface; but later experiments have shown that this is more than sufficient, 8·1 square feet per horse-power being all that is required. Vertical surface is considered only half as efficient as horizontal surface.

The rule for the nominal horse-power of a boiler may now be given. It is exceedingly simple. Let $s$ equal the whole horizontal heating surface, plus half the vertical heating surface in square feet, then will the horse-power of the boiler be

$$HP = \frac{s}{8{\cdot}1}$$

When we have cylindrical surfaces to deal with, other rules will be found more convenient. If, for instance, the furnace is contained in a cylinder, so that the flame and hot air act on the upper half of the tube, then the horse-power to which the surface thus afforded is equivalent may be found from the formula

$$HP = \frac{l\,d}{5}$$

$l$ and $d$ being the length and diameter of the tube in feet.

Many boilers are now made in which the heating surface is fur-

nished principally by small tubes, such boilers being known as multitubular boilers, and in calculating the power of these it will be inconvenient to take the diameter of the tubes in feet, in consequence of their small size. Hence, a rule must be found for the diameter in inches. In this case, the heated air acts on the whole surface of each tube; hence if $n$ be the number of tubes, $d$ the diameter in inches, and $l$ the length in feet, the following rule will give the power:

$$H P = \frac{n\,l\,d}{30}$$

It may be advisable to consider the effect of size of the tubes, with regard to heating surface, it being taken for granted that a certain section is required for draught, which section is to be given by a number of tubes.

Let $n$ equal the number of tubes, $d$ the diameter of one tube in inches, $a$ the total area of air passage in square inches; then the quantities may be found from the following equations, $l$ being the length of tubes in feet:

$$a = 0{\cdot}7854\, d^2 n$$

but

$$H P = \frac{l\, d\, n}{30}$$

hence

$$a = \frac{706\, \overline{H P}^2}{l^2 n}$$

From this formula it will be seen that the area varies as the square of the horse-power, and inversely as the number of tubes, and the square of the length; therefore, the smaller the tubes are made, the greater will be the heating surface in proportion to the area of the air-passage, and more heat will be taken up from the gases in their passage; wherefore we may conclude that it is desirable to make the tubes as small diameter as possible. The following formula may, in addition to those already given, be found useful:—

$$l = \frac{30\, H P}{d\, n}$$

$$n = \frac{30\, H P}{l\, d}$$

$$d = \frac{30\, H P}{l\, n}$$

also, if a given area of section be required

$$d = \sqrt{\frac{a}{0.7854 \cdot n}}$$

$$n = \frac{a}{0.7854\, d^2}$$

Small tubes have also other advantages over large ones, for they may be made of thinner metal, because the strain diminishes as the radius, and the tubes being thinner will be lighter, and will interfere less with the passage of the heat from the hot air to the water to be evaporated. The following rule will give the thickness of the tubes: Let $s$ be the tensile resistance of an inch square bar of the material in pounds, $c$ the compressive resistance of the same, $r$ the radius, $p$ the pressure in pounds per square inch, $t$ the thickness, in inches, of the metal; then, if the pressure acts outside the tubes, and the tubes are short and rigid, their thickness should be

$$t = \frac{pr}{c}$$

If the pressure be applied on the inside, the thickness will be

$$t = \frac{pr}{s}$$

The first formula must not be applied to tubes which are not rigid, and which will therefore yield by the buckling or crumpling of the material of which they are made.

Square boilers, such as those generally used for marine purposes, are strengthened by stays, which tie the flat sides and prevent their bulging when subjected to internal pressure.

Boilers should always be fitted with safety-valves and steam-gauges, the construction of which will presently be described.

# CHAPTER XI.

## PRELIMINARY CONSIDERATIONS ON THE APPLICABILITY OF VARIOUS KINDS OF STEAM-ENGINES TO VARIOUS PURPOSES.

THE first step to be taken when it is proposed to construct a steam-engine, consists in determining the general form of the main features of the engine, without regard to the minor details; wherefore, it is proper to enter upon this subject before following up complete descriptions of steam machinery.

This chapter will be devoted to a comparison of the different arrangements already mentioned, regard being had only to the main features; such as cylinder, connecting rod, beam, crank, &c., as applied to a variety of purposes.

Steam-engines will be first divided into condensing and non-condensing, the former being the most costly in construction, and taking up a great deal of room, but making full amends for this in the economy with which they work. The latter kind of engine is exceedingly compact, and capable of working at very high speeds, simple in construction, and cheap, occupying a small space, but very far inferior to the condensing engine in point of economy of fuel.

Engines may also be divided into three classes: stationary, marine, and locomotive. In the stationary class, we have subdivisions according to form, as follows: beam engines, vertical engines, table engines, horizontal engines, inclined engines, oscillating engines, pendulous or inverted oscillating engines, grasshopper engines, rotatory engines, and disc engines.

Marine engines may be divided into the following classes: first, paddle engines and screw engines, according to the method of propulsion; secondly, according to the form, into side-lever engines, upright engines, inclined engines, oscillating engines, horizontal engines, rotatory engines, disc engines, &c.

Locomotive engines include those for railway purposes and

those which run on common roads. They may be divided into two classes: one with the engines above the boiler, and the other with the engine beneath it. They are invariably high-pressure, as it is necessary that they should occupy but small space, and be as light as possible.

Let it be required to design an engine for manufacturing purposes, then it will be necessary to consider which class of engine will be most suitable to the purpose, a rotatory motion being supposed to be required. If the neighborhood in which the engine is to be erected be plentifully supplied with water, then it will be advisable to construct an engine on the condensing principle, for the sake of economy of working. If, however, there be not room for the bulky machinery required, then a high-pressure engine must be employed. The beam-engine will be found to work very steadily, and is perhaps the most convenient form that can be adopted when a high velocity is not required; but if the speed must be considerable, then an engine of lighter parts will be preferable. It may be desirable to examine the action of reciprocating masses thus employed.

Examining the action of the engine during one stroke, we find that we have the piston, piston rod, &c., in a state of rest at the commencement of the stroke. These bodies are then set in motion, their velocity gradually increasing, but before the next stroke can be made, the work accumulated in these parts must be absorbed, and the manner in which this absorption is effected is one of vital importance. If the steam be simply cut off, then this work accumulating in the above-mentioned masses of metal will evidently be expended upon the bearings and joints; but if the method usually known as cushioning be adopted, the greater part of the accumulated work will be economized. By cushioning the piston is meant the introduction of the steam for the following stroke, before the termination of the previous one; then the greater portion of the work accumulated will be expended in compressing the steam, and so soon as the crank has passed the centre, or dead point, the piston will change the direction of its movement, and the compressed steam will expand, and give up the work which it had absorbed; hence the reciprocating engine may by careful management be caused to work with great smoothness and regularity. In the more compact class of steam-engines, such as table-

engines, horizontal, inclined, and vertical-engines, a less degree of cushioning is required than in beam-engines: because in the former case the moving masses do not possess so much inertia as do those of the latter class of engines. It has been proposed to use masses of metal to counterbalance the effects of the reciprocating parts of steam-engines, being of equal weight with the latter, and always moving in an opposite direction. This, however, is perfectly superfluous for fixed engines.

With regard to rotatory-engines, it may be desirable to offer a few remarks in this place. In these machines there are no reciprocating parts having sufficient inertia to render them worthy of serious consideration, wherefore, high velocities may safely be used. There is also the advantage on their side, in point of uniformity of movement, as the moment of power about the main shaft remains constant for any position of the same, the variations entailed by the crank being thus avoided.

It is a great mistake to imagine that any saving is effected by having an exceedingly heavy fly-wheel, to render less evident the jerks and reactions produced by the reciprocation of the machinery of the ordinary engine; for although the velocity may be thereby rendered more uniform, yet the jerks and vibrations will still exist, although they be less evident. Hitherto rotatory engines have not been attended by results sufficiently satisfactory to induce their employment by the generality of mechanical engineers: this being due, in a great many engines, to the impossibility of keeping the valves and packings in a steam-tight condition, which defect destroys the economy of the machine, a large quantity of steam being lost by leakage, the difference between the surfaces of contact of the moving parts of the two classes of steam-engine being as follows: In the reciprocating engine surfaces of contact of any desired extent may be obtained, and these surfaces may be scraped so as to work upon each other almost perfectly steam-tight; whereas with rotatory engines it is but seldom that good steam-joints can be obtained, the engineer being, in the greater number of cases, obliged to substitute these broad surfaces of contact by others so narrow, that, practically speaking, they may be regarded as simple lines.

From these remarks it may be concluded that for the purposes above mentioned, where great steadiness is required, beam-engines

may be used with advantage. Next to these, with regard to uniformity of movement, oscillating engines may be ranked, more especially when constructed with the cylinders above the main shaft, which form is known as the pendulous engine; and if this be made with a proper regard to the principles which regulate the motion of vibrating masses it will be found to work with great smoothness.

With regard to marine engines, the following remarks will embody most of the considerations by which the engineer is directed to a conclusion as to the class of machine to be employed for any particular vessel.

The first consideration is the available space, which is generally rather in defect as regards height, of that which is most convenient; hence from time to time various means of overcoming this inconvenience have been devised. The first consisted in the employment of beams, placed beneath the cylinders, with connecting rods attaching their extremities to the piston rod and to the crank; oscillating engines have, however, been found, on the whole, most convenient for paddle-wheel engines.

The introduction of the screw-propeller has given rise to a great variety of designs, the main objects being to shorten the screw shaft as much as possible, and to let the engines act upon it direct; that is to say, without the use of tooth wheels, or spur gearing, as it is generally called.

With regard to locomotives, there is but little to be said, the circumstances of the case requiring always a compact design, and admitting only, in the present state of science, of the use of horizontal or inclined engines, with fixed cylinders. These cylinders are sometimes placed within the framing of the engine, and below the boiler, and at other times on the outside of the framing.

In concluding these general remarks, it is thought desirable to direct the reader's attention to the accompanying Plate, No. XI., illustrative of the main features of various descriptions of engines; the lettering is the same on all the figures:—*a* is the cylinder, *c* the piston rod, *d* the beam, *e* the connecting rod, *f* the crank, *g* the main shaft, and *h* the eccentric, by which the valves which admit the steam to the main cylinder are worked.

## CHAPTER XII.

### ON THE DETAILS OF STEAM-ENGINES.

*Cylinders and Valves.*

PRELIMINARY theoretical and general practical considerations having been discussed, the next step to be taken will consist in an account, principally of a descriptive character, of the various details or elementary parts of steam-engines as they exist, without regard to the purposes to which they are applied; and in following out this course care will be taken to describe fully every peculiarity of form, and to indicate the end intended to be gained by such peculiarity, without, however, entering into any considerations of a purely theoretical character.

One of the most general details of all classes of steam-engines is the steam-cylinder, which will therefore first require attention. Cylinders may be divided into two classes, fixed and oscillating.

Fig. 44.

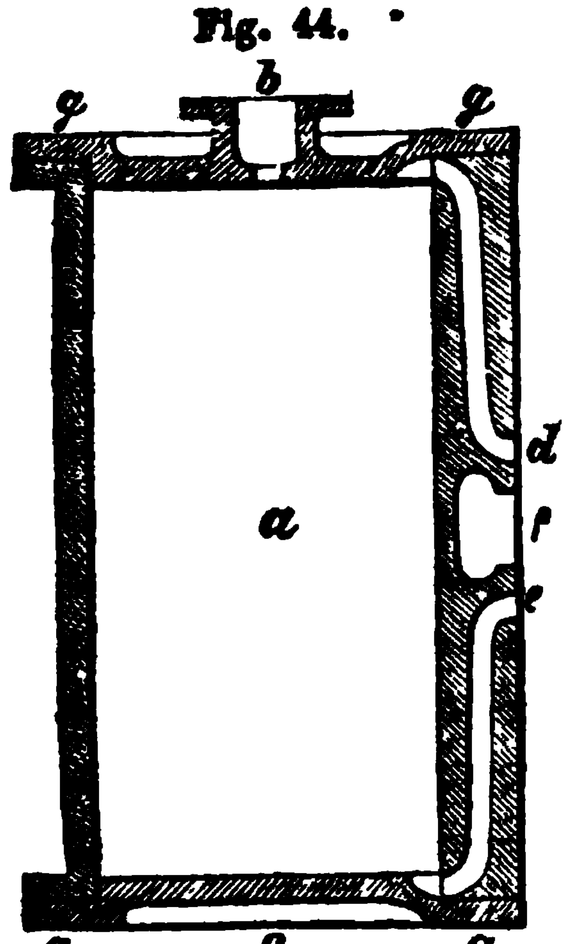
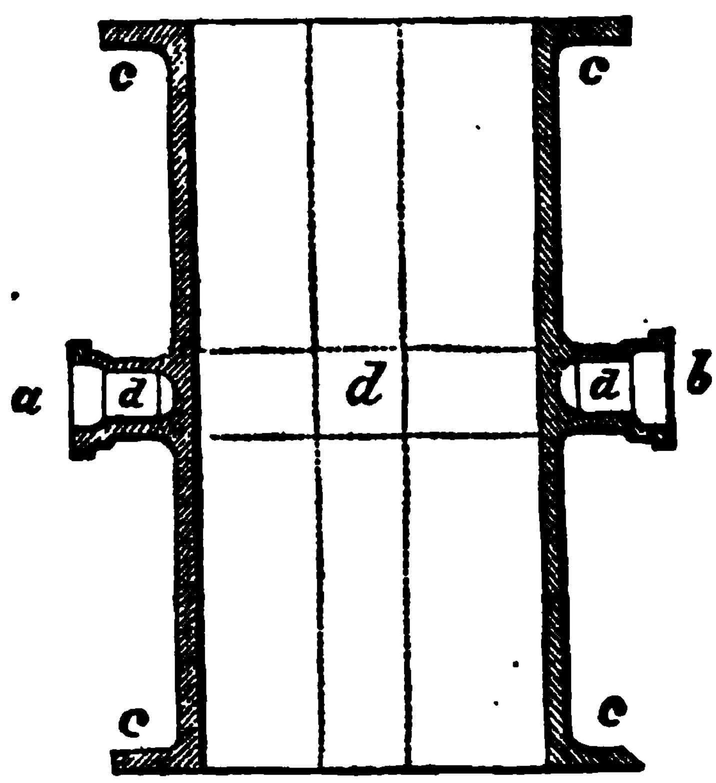



Fig. 44 represents a section of an ordinary fixed cylinder; that is to say, it exhibits the form of a cylinder which has been cut through the centre, the cut parts being exposed to view in plan or vertical section. It is of course circular; *a* represents the body of the cylinder, *b* and *c* are covers, of which however the description will be postponed for the present, the body or central part of the cylinder being first considered. It is necessary to provide means for the entrance and exit of steam to and from the upper and lower parts of the cylinder; the extremities of the passages through which the steam passes from the steam chest to the interior of the cylinder are shown at *d* and *e*, *f* indicating the entrance to the pipe through which the steam, having done its

work, makes its escape. These entrances are called ports, and will subsequently be fully described. The body of the cylinder is furnished at top and bottom with rims called flanges, which serve for the attachment of the covers by means of bolts and nuts, at *g g g g*.

Fig. 45 represents a section of an oscillating cylinder, taken at right angles to the ports. The feature which distinguishes this class of cylinder from the foregoing, consists in the manner of

FIG. 45.



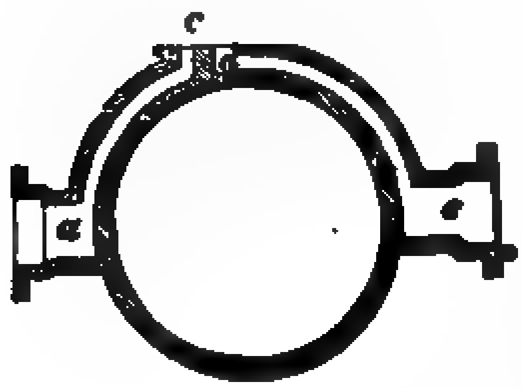

supporting it, so that it may oscillate with ease. *c c c c* are the flanges, the covers are not shown. *a* and *b* are, as it were, short shafts, cast on the sides of the cylinder, and diametrically opposite to each other; they are accurately turned, and are supported in bearings which fit them truly. These short shafts are termed trunnions, the parts which rest on the bearings being in this, as in other cases, called journals.

It is evident that the motion of the cylinder precludes the use of the method of attaching the steam-pipe commonly employed in fixed engines, hence some peculiar form of construction must be had recourse to; wherefore, the steam is conducted through the trunnions, to and from the valve chest. The means of making a steam-tight joint, between the fixed steam-pipe and the moving trunnions, will be explained in a subsequent page. The steam is conducted from one trunnion to the steam-chest by a hollow band passing round the cylinder, and in a similar manner from the steam-chest to the other trunnion, after having done its work in

propelling the piston; its passage may however be better described by the assistance of the horizontal section Fig. 46, which is taken through *a b*, the steam-band in the former being represented by the dotted lines *d*.

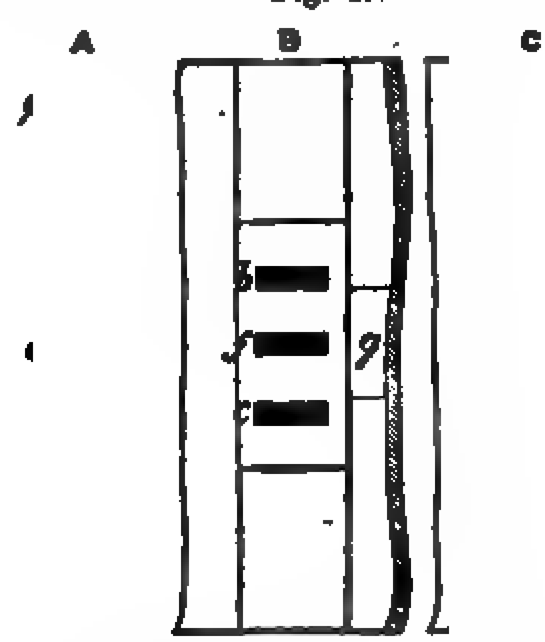
In the horizontal section, Fig. 46, the shaded parts represent the metal, *a* and *e* being the trunnions. The steam by which the engine is to be impelled enters at *a*, and passes thence into the steam-chest at *c*, after which it is admitted by the slide valve to the cylinder, and having done its work, passes into the exhaust port *d*, and finally out at the trunnion *e*, into the condenser or atmosphere, as the case may be.

Fig. 46.




The steam-ports attached to the cylinder, and forming part of

Fig. 47.




the same, next require description. In Fig. 47, *A* is a section taken through the cylinder, that part, however, which shows the ports only, being given; *B* is a front elevation of the ports, and *C* is a section produced by a plane cutting the steam passages by passing through the centres of the vertical parts of the same, parallel to the port-faces. The lettering is the same in each case; *a* is the interior of the cylinder, *b* and *c* the steam-ports or external openings of the steam-passages, which are made narrow in order that they may be suddenly opened and closed by a slight movement in

the direction $b\ c$ of a plate resting upon the port-faces; $f$ is the port into which the exhaust steam passes, whence it escapes through the exhaust pipe $g$. The means by which the entry and exit of the steam are regulated will be described in a subsequent page, hence no further comment upon the port-faces is requisite, except the observation that the steam-passages may be shorter, the ports wider apart, and the port-faces sometimes made in two separate parts: one for the top face, and the other for the bottom.

Having now fully described the form of the steam-cylinder, it is necessary to render some account of the means employed in its manufacture.

The first step towards the construction of the cylinder will consist in determining its dimensions, and in order to obtain results of a satisfactory character, we must necessarily employ proportions which may be demonstrated to be the most economical. With regard to the diameter of the cylinder requisite for a given horse-power, that will be found in the following formula.

Let $h$ = the horse-power required.

$n$ = the number of revolutions of the main shaft per minute.

$l$ = the length of stroke

$p$ = the total effective pressure per square inch and pounds upon the piston.

$d$ = the diameter of cylinder in inches.

Then:

$$d = 145 \sqrt{\frac{h}{l\,n\,p}}$$

which formula is derived from the considerations given in a previous chapter. We may here observe that $p$, the total effect of pressure, is taken to represent the mean pressure of the steam for high-pressure engines, and the mean pressure of steam plus the mean pressure of vacuum in condensing engines. For the latter class, there is a rule for nominal horse-power, the pressure being taken at seven pounds per square inch, and the speed of the piston at two hundred feet per minute. Working out the calculation upon these data, the following formula will be found to approach absolute truth very nearly

$$d = 5{\cdot}5 \sqrt{h}$$

These rules will suffice for the diameter of the cylinder, but it yet remains for the engineer to determine the thickness of metal. The absolute thickness requisite to withstand the bursting-force is much less than can be applied in practice, hence the formulæ assumed to meet this requirement only are of little practical value; we therefore insert one of a somewhat different character, which satisfies the conditions required by the increasing weight of the cylinder. We insert the formula without giving the steps by which it was obtained, for the two following reasons; firstly, space would thereby be occupied in a manner which is undesirable in a work intended for practical reference; and secondly, they are of so simple a character that little difficulty can be found in their comprehension.

Let $t$ = the thickness of the metal in eighths of an inch, then:

$$t = \frac{p\,d}{440} + \sqrt{d}$$

$$= \sqrt{d}\left\{p\,\frac{\sqrt{d}}{440} + 1\right\}$$

It is almost needless to observe that in this formula the value of $p$ must be taken at a maximum. It may be desirable here to insert an example illustrative of the use of these formulæ.

Let a cylinder be required for a condensing engine whose nominal power is sixty horses, then the square root of sixty is?

7·75 nearly;

hence,

$$d = 5{\cdot}5\,\sqrt{h} = 5{\cdot}5 + 7{\cdot}75 = 42{\cdot}6 \text{ inches}$$
$$= \text{say } 43 \text{ inches.}$$

For the thickness of metal, supposing $p = 30$ lbs., will be found,

$$t = \frac{p\,d}{440} + \sqrt{d}$$

$$= \sqrt{d}\left\{\frac{p\sqrt{d}}{440} + 1\right\}$$

$$= 6{\cdot}55\left\{\frac{30 \times 6{\cdot}55}{440} + 1\right\} = 6{\cdot}55 \times 1{\cdot}446 = 0{\cdot}947 \text{ eighths.}$$

The thickness will therefore in practice be made one inch.

It frequently happens that the cylinder is strengthened by

bands passing round it, but cast in the piece with the cylinder itself.

The next step will consist in drawing sections, plans, and elevations of the cylinder to scale, care being taken to delineate accurately the ports and steam passages, which latter it will be found desirable not to bring quite through the metal; but on the contrary, it will be preferable to leave the ends closed by a slight film of metal, for reasons which will subsequently be mentioned. The drawings being made, the pattern-maker may prepare a template and core-boxes; the former will correspond to the general exterior profile of the cylinder, and the latter will contain cavities similar to those which form the steam passages, in order that cores of a proper form to exclude the liquid metal from those passages during the process of casting may be prepared. The mould will then be made in *loam*, and the cylinder cast according to a method similar to that described for the production of a melting-pot in the chapter on Moulding and Casting.

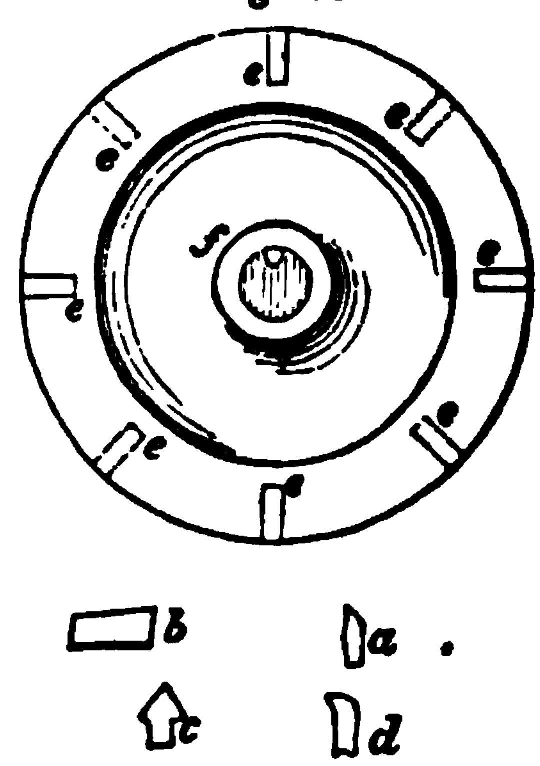
Small cylinders may, however, be cast by the ordinary means, in which case a pattern will be required, such pattern representing the general external form of the cylinder, but with this exception, that wherever an aperture is to be formed in the cylinder there will be a protruding piece, called a *print*, on the pattern, in order to form recesses wherein the extremities of the cores requisite to produce such apertures may be inserted, in order to afford them requisite means of support. These cores may also be further supported and retained in position by means of broad-headed nails, driven into the sand. The casting is subsequently conducted in the usual manner. When the casting is cool, it is carefully examined, and if defective, it is put aside to be remelted, being known as a waster; but if perfect, it is first treated with a piece of hard oven coke, with which it is well scoured, in order to remove the greater portion of the hard silicious coating with which it has become covered, on account of the heat of the molten iron vitrifying a portion of the sand in its neighborhood. After scouring, the cylinder may be further cleansed by means of an old coarse file, after which it will be ready to be handed over to the turners and fitters, whose operations upon it next require attention.

The first operation to which the cylinder will be subjected by

the turner, will consist in boring the cylinder, cutting off the head or runner, and facing the flanges; and it is in this operation of boring that the advantage of casting the cylinders with the steam passages closed is observed; for if the cylinder were cast with it open, the cutting tool would be damaged by the concussions produced every time it passes over the opening; and after the boring the thin film of metal left may readily be cut away with the chisel, and the edges of the ports filed smooth. We have already described the boring-bar and head in the chapter on Workshop Machinery, but nevertheless deem it desirable here to insert an illustration of the boring-head, and cutting tools commonly used with it.

In Fig. 48, the upper sketch represents a boring-head made of cast-iron, and accurately bored in the centre, and turned upon the periphery. The boring-bar upon which it travels from end to end is shown by the shaded part at *f*; *e e*, &c. are slots in which the boring tools are fixed by wedges, the boring-head being slightly less in diameter than the interior of the cylinder to be bored. The head is first used with the tool shown at *a* and *b*, which acts almost as a scraper, but which is sufficiently accurate in its action to take the rough cuts satisfactorily. The finishing cut is taken with the point tool shown at *c* and *d*; and in taking this cut it should be borne in mind that as, by the friction of boring, the cylinder becomes heated, and therefore expanded, the operation should not be stopped a sufficient time to allow it to cool and contract, whereby a sudden variation in the bore would be produced.

Fig. 48.



It will be observed that there are great difficulties in boring cylinders, when compared with the process of turning, as the cutting-tools in the former operation can scarcely be brought into operation at a less angle than 90°; hence they must of necessity act rather as scrapers than as cutting tools properly so called.

In the most accurately-turned cylinders we see that the interior form is not that of a perfect cylinder, but of a frustrum of a cone

of very small angle, that is to say, with very little taper, this form being thus produced. On starting the work the cylinder is cold, but as the boring proceeds it becomes heated, which effect will not be noticed in the boring-head, but only in the cutting tool. The result is that the cylinder expands while the radius of the cutting edge remains almost constant. Hence that end of the cylinder at which the boring was commenced will ultimately possess a diameter somewhat greater than the other parts; but the difference is far too trifling to be taken into account in practice. Nevertheless, it is desirable to be acquainted with the true state of affairs.

The cylinder, finished with the point-boring tool, presents on its interior surface the appearance of a screw furnished with an extremely delicate thread. Hence, it may readily be believed that with a new cylinder there is at first much friction; but in a few days the roughness wears off, and the interior of the cylinder becomes perfectly smooth and bright.

A just consideration of these facts leads to the conclusion that it is unfair to test the powers of an engine immediately after it is erected; and that results more nearly approaching the truth may be readily obtained after the machinery has been at work for a few days.

The method of boring the cylinder having been discussed, it will be necessary to pass on to the other operations connected with the formation of this important element, which contains, as it were, the vital force to which the mechanical movements of the steam-engine are due, and upon which they are dependent.

The next operation will consist in facing the flanges, which may be done by attaching a temporary slide apparatus to hold the cutting tool, in order to allow a motion of the same from the interior of the cylinder towards the exterior, the cut being commenced at the internal edge of the flange. The method of completing the cut is obvious, hence no further description of it is necessary

The next step will consist in the preparation of the port faces upon which the valve which regulates the admission of steam to the cylinder moves. These port faces are first planed and filed, and then reduced to a surface as nearly plane as can be obtained by the following means:

A surface-plate of the form already described in a previous chapter, is smeared with ruddle or other similar coloring-matter,

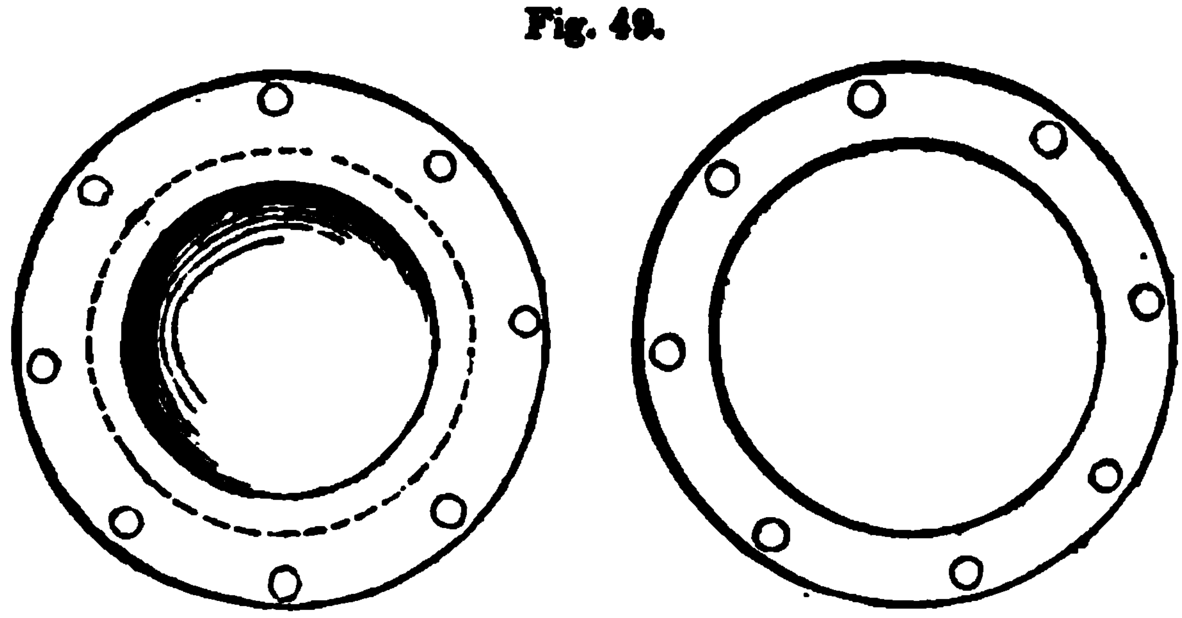
and then placed upon the port faces and gently moved about in contact with them; then it is evident that those points on the port faces which are most elevated will alone be in contact with the surface-plate, and therefore will become marked with the coloring-matter. The highest points in the surface will become thus indicated by the coloring matter taken up by them, and may be reduced by scraping. The operation with the surface-plate is again and again repeated, until it is found to bear uniformly upon the port faces. The method of adjusting the slide to the port faces will subsequently be described.

The foregoing operations having been satisfactorily conducted, it remains to drill in the flanges of the cylinder the holes through which the bolts by which the covers are attached to the cylinders pass; and also the bolt-holes in the port face flanges by means of which the slide-jacket will subsequently be attached.

If the cylinder be intended to oscillate, it will be furnished with trunnions, which must of course be accurately turned.

The cylinder-covers will not require attention; they may be classed under two heads,—plain covers, and covers furnished with an air-tight stuffing-box to allow a rod to work through it, air and steam-tight. One of each class is usually required. A section of the plan is shown at the bottom of the cylinder, Fig. 49. This is the form generally used for small engines. In larger ones it will be frequently convenient to make the covers concave on the inside, thereby affording extra strength. It is of course circular in plan. The upper cover will be similar in every respect, except that an

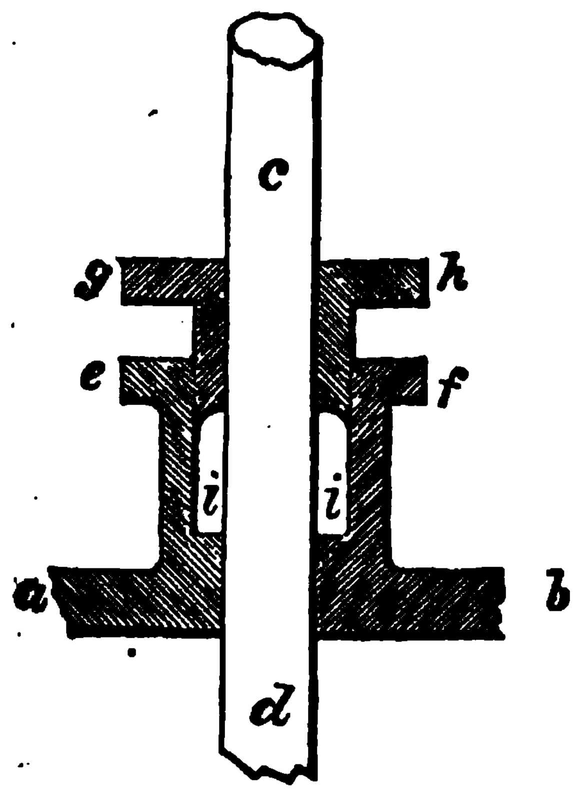
Fig. 49.



air and steam-tight aperture must be provided for the passage of the piston-rod. The cylinder covers must be turned on their peripheries, and holes must be drilled in them corresponding with those in the flanges of the cylinder.

The reader's attention will now be directed to the means usually employed when it is requisite that a rod should work through an aperture, air and steam-tight. This is effected by means of a contrivance called a stuffing-box, furnished with a gland.

Fig. 50.




In Fig. 50 is shown a section of a stuffing-box and gland; *c d* is the rod, which is required to work air and steam-tight through an aperture in the plate *a b*. Upon this plate, and in one piece with the same, is cast a cylindrical box, or cylinder, furnished at the top with a flange, *e f*; this box, technically termed the stuffing-box, is bored at the bottom accurately to fit the rod *c d*, and at the upper portion it is bored out somewhat larger, as shown, to have a cylindrical cavity round the piston rod. To this box is fitted a gland, which gland is, in fact, a cylinder furnished with a flange, *g h*. This cylinder, or gland, is bored throughout its length so as to fit accurately the rod *c d*, and its exterior surface is turned down to such a diameter that it may slide with ease into the stuffing-box already described. A closed space, *i i*, will then exist round the rod *c d*. This space is filled with greased hemp, as packing, or with some other suitable material. The bottom of the gland is not faced up flat, but concave, as shown: the bottom of the stuffing-box being similarly formed in order to force the packing against the rod *c d*; but with some kinds of packing this construction is dispensed with, flat faces being used. The packing is compressed by tightening up the bolts *e g*, &c., whereby the gland is forced into the stuffing-box. The gland, if small, may be fixed in a dog-chuck, and bored out by a side tool; but if very great accuracy is required a small boring-bar may be used. For boring articles similar to glands, the following contrivance is very convenient. A small boring-bar is fixed in an ordinary drilling machine, the boring-bar being furnished with slots, in which cutting tools may be firmly fixed. This bar passes through a circular aperture in the centre of the drilling table, being thereby steadied. The work to be bored is

accurately fixed upon the centre of the drilling table, the boring-bar passing through its axis.

A proper boring tool being fitted to the boring-bar, the boring of the work is proceeded with, the cutter being caused to descend as the boring proceeds by means of the usual feed-motion of the drilling machine.

In many cases the stuffing-box is lined with brass, and the gland either lined with brass or made entirely of that metal.

The foregoing description of a steam-tight aperture will answer generally for every case where a rod is required to work as above, no matter whether it be a piston-rod, slide-rod, or other similar element.

The next details to be considered are those referring to the admission of steam to cylinders of the oscillating class. We have already mentioned that the steam is admitted through one trunnion, and exhausted through the one opposite, and it now remains to describe the connection between the trunnion and the steam-pipe.

Two methods of constructing this joint will be described. In the accompanying Figs. 51 and 52, *d e* is a portion of the cylinder, *c* the steam-band surrounding it, *b* the interior of the trunnion, *h h* the portions embraced by the trunnion bearings whereby the cylinder is supported, *a a* the extremity of the steam-pipe. This steam-pipe is at rest, while the trunnion oscillates so that it has a circum-

Fig. 51.

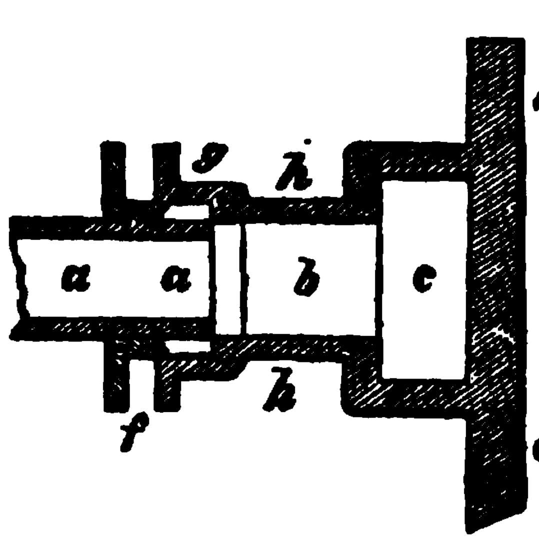
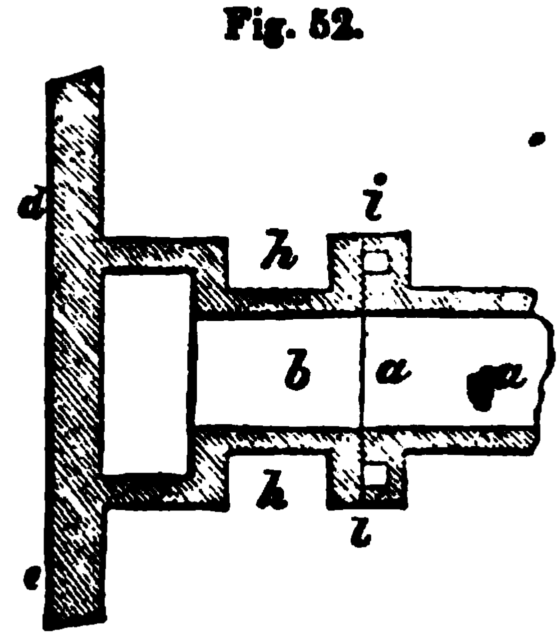



Fig. 52.




ferential motion about the steam-pipe. In Fig. 51 the joint is made steam-tight by enclosing the extremity of the steam-pipe within the stuffing-box, as shown: it being necessary, in forming

the parts, to bore the trunnion and gland, and to turn the extremity of the steam-pipe so that it shall fit accurately the interior of the trunnion. The arrangement of the Fig. 52 is, however, much simpler, and, we think, preferable. In this case no gland is used, but the ends of the trunnion and steam-pipe are faced, and rest in contact with each other, the joint being kept steam-tight by a ring, *i i*, let into a recess in the extremity of the steam-pipe. By this method the boring of the trunnion and the turning of the steam-pipe are avoided.

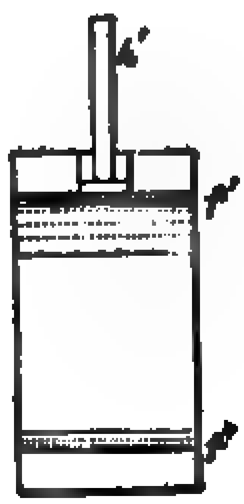
The reader's attention will now be called to the means of admitting steam to each extremity of the cylinder, and allowing of its escape at the termination of the stroke. It will be necessary in the first place to consider what requires to be done; and, in the next place, the various means of doing it, avoiding however encumbering the space at disposal with accounts of methods displaced by modern improvement.

There exist in the neighborhood of the cylinder two pairs of passages; the first pair have each one extremity communicating with the valve arrangement, their other extremities communicating with the interior of the steam-cylinder,—one communicating with the top, the other with the bottom of the same. We have also the second pair of passages,—one connects the boiler with the valve arrangement, whilst the other connects the valve arrangement with the exhaust,—and what is required to be done is this: To let the top passage to the cylinder communicate with the boiler when the bottom passage is open to the exhaust, and *vice versâ*; and this has to be done in a peculiar manner, in order to cause the engine to run in the direction desired, and to prevent the possibility of its reversing itself.

It is desirable to commence the description with the simplest form of valve, and then to proceed by steps to the more complicated. Fig. 53 represents a section of the steam-ports and short slide-valve, surrounded by the steam-chest, and also a view of the back of the valve; *a b* is part of the interior of the cylinder, the steam-passages opening into the cylinder at *a* and *b*; *x* is a portion of the piston; *c* and *d* are the external steam-ports, *e* being a port leading to the exhaust (for front view of port faces see Fig. 47); upon the port faces slides a box, *f f*, called a short slide-valve; the box is of such width as to cover the ports, and of such length as

to cover one steam-port and exhaust-port; *k k* is the steam-chest, which is bolted on to the port faces, and within which the slide-

Fig. 53.



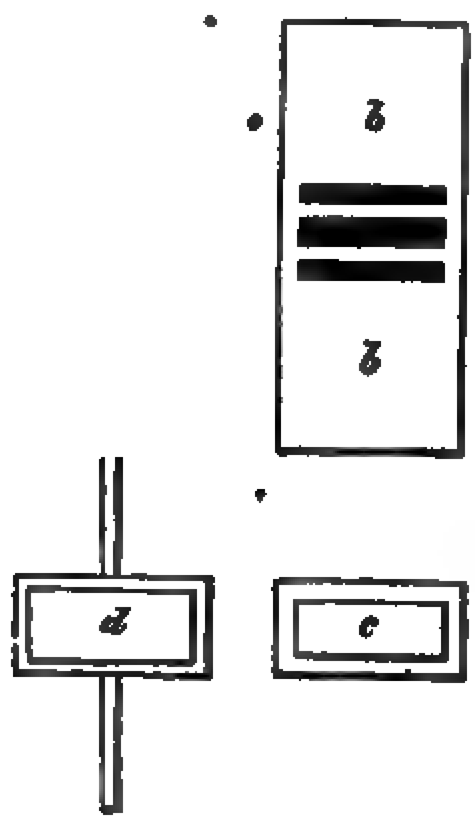

valve moves. The surfaces of contact between the slide-valve and the port faces are planed and very accurately finished by means of a planometer, and making the two surfaces act as planometers to each other, so that no steam shall escape through the valve. The steam-chest, *k k*, is kept full of steam by means of a pipe coming from the boiler, the extremity of which is shown at *l*. The slide-valve is moved by means of a rod (*h*) passing through a gland in the steam-chest; *h' f' f''* show a back-view of the valve. With the valve in the position shown it is evident that the steam entering the steam-chest will pass through the port *d* into the bottom of the cylinder at *b*, and the steam in the upper part of the cylinder will pass out through the passage *a c* into the cavity of the slide-valve, and thence into the exhaust port *e*. When the valve is moved into the position shown by the dotted lines *g g*, the direction of the steam will be reversed, the steam in the chest entering the upper part of the cylinder, whilst the steam in the lower part of the same passes out through the valve into the exhaust. The valve is kept close up to the port faces by the pressure of the steam acting at the back of it, which is much in excess always of the pressure on the interior of the valve, because that cavity con-

stantly communicates with the exhaust-port. This valve is exceedingly compact, and very generally used. In order to insure the motion of the engine always in the desired direction, it is necessary that the steam-port should be partly opened before the commencement of each stroke; or, in other words, that it should be in advance of the piston. This is called giving the valve a lead. In order to cut off the steam at an earlier period of the stroke than would ordinarily be accomplished by the valve, its edges are made somewhat wider than the steam ports. This is known as giving the valve lap.

Slide-valves of the foregoing form are in some engines, such as locomotives, made exceedingly short, in order to reduce as much as possible the motion, or travel as it is called, of the valves. The slide-valve is then frequently moved by a frame which surrounds the box part of the valve, having attached to it rods which pass out at the ends of the steam-chest. By this arrangement the valve can readily adjust itself to the pressure which keeps it up to the port faces without straining the valve rods.

In Fig. 54 views of the very short slide-valve are shown: *a* is a section of the valves, steam passages, and chest; *b*, a front elevation of the ports, which are long and narrow; *c*, a front view of the slide; and *d*, the slide rod and frame. It is evident that with these narrow ports a very slight movement of the valve is sufficient to open and close them.

Fig. 54.




The next valve described will be a long valve, which is, however, in some respects, somewhat similar to the foregoing short slide.

It may here be mentioned, before proceeding farther, that the number of pieces in which the steam jackets are made may be determined from the figures by observing the occurrence of flanges whereby the various parts are bolted together.

Fig. 55 represents a section of the slide mentioned above. It is a long tube; *a* and *b* are the steam-passages, *c* is the exhaust-port, *k* is a hollow in the metal to lighten the cylinder-casting, *d e* is the slide, *f f* the steam chest, and *g* the slide rod. With the slide in the position shown, it is evident that the steam in the chest will pass round the slide into the bottom of the cylinder at *b*, and the steam in the upper part of the cylinder will pass through the whole length of the slide rod into the exhaust *c*. When the valve is raised to the position shown by the dotted lines, the steam from the chest will pass through *a* into the upper part of the cylinder, while the steam in the lower part passes into the valve and thence to the exhaust, the aperture at the lower part of the valve *d* being

Fig. 56.

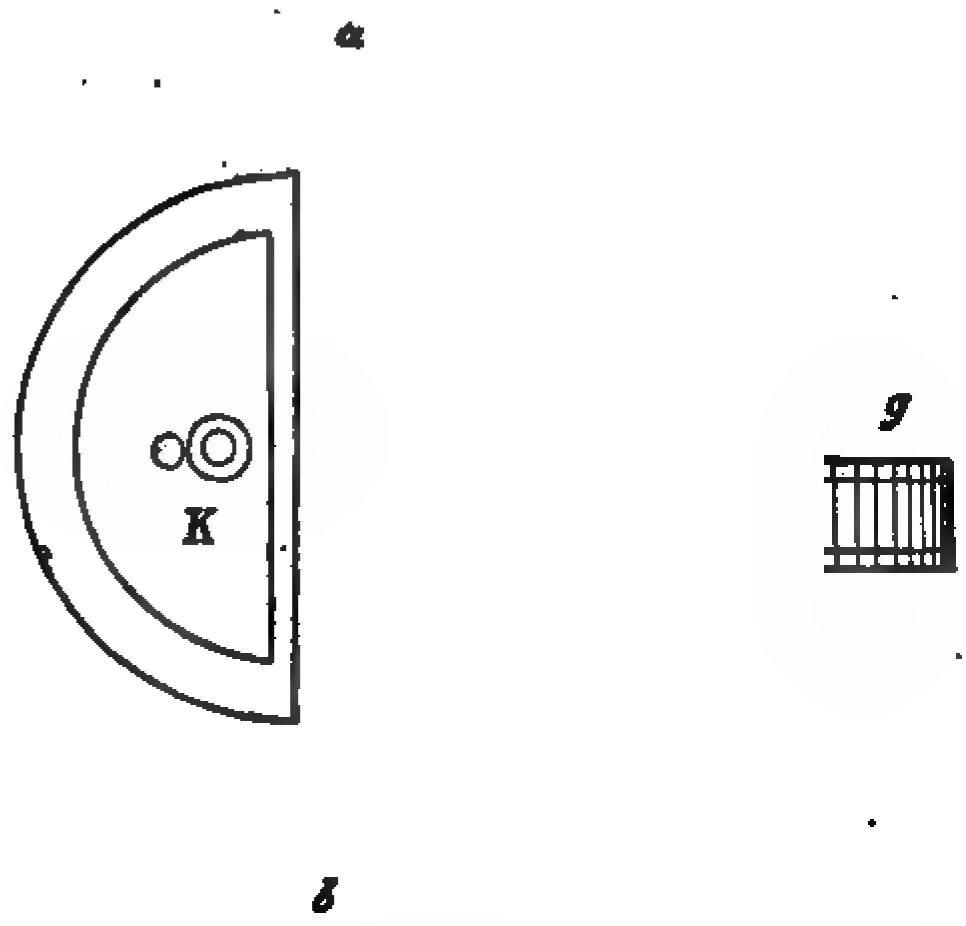
sufficiently wide to cover the ports *b* and *c*. The apertures at the extremities of the slide-valve are of course rectangular, which form is gradually changed to circular or elliptical in the centre part of the tube. The port faces are in every case surfaced as above described. With this long valve it is found necessary to

have a light spring *l*, to press it against the port faces, otherwise, when the steam is shut off, it will fall away. The slide jacket is made of a semicircular or D shape, or oblong, as shown at the horizontal section *m*, which section is formed by a plane cutting the slide on the line *n n*.

The next valve to be considered is the D valve, of which views are shown, Fig. 56; this, like the former, is a long valve.

In Fig. 56, *a* and *b* are the steam-passages to the cylinder, *c* and *d* are two D-shaped slides, as shown in place at *f*, these slides being connected by a hollow pipe; *c d e* is the exhaust pipe, which, contrary to those already described, is independent of the cylinder, proceeding from the steam-chest. The D-shape valves

Fig. 56.




are accurately fitted to the steam-jacket, which is truly shaped up, being rendered steam-tight at the back or convex part by metal slips pressed against the steam-jacket by springs; these slips being shown at the elevation *g*, and at the enlarged section *k*. The

slides are moved by a rod *h*, attached to a lug on the front part of the upper valve. The steam is admitted between the D-shaped slides, and in the position shown it is evidently passing through the passage *b*; the steam in the upper part of the cylinder is passing into the steam-jacket, thence through the tube *c-d* to the exhaust pipe *e*. If the slides be now caused to rise above the ports, as shown by the dotted lines, then it is evident that the steam will flow into the cylinder at *a*, and out of the bottom of the cylinder at *b* into the exhaust.

Fig. 57. Fig. 58.

It is not absolutely necessary in this form of valve to make the steam-jacket continuous, but it may be made in two parts, as shown, Fig. 57; the tube connecting the slides being carried through stuffing-boxes, in each of the short steam-jackets. The steam is admitted to the inner end of each steam-jacket, that is to say, to the parts nearest *c d* in Fig. 56. In the position shown, the steam is passing into the bottom of the cylinder, and out of the

upper part of the cylinder, through the connecting tube into the lower jacket, and thence into the exhaust pipe.

Fig. 58 represents a very ingenious form of long valve. The valves consist of two round slides or pistons, fitted with packing rings, pressed outwards with springs. The steam is admitted at *o* between the slides, and around the valve jacket at each end is a casing communicating with the exhaust, and also, nearer the centre of the jacket, there are circular passages, *a a*, *b b*, communicating with the steam-ports *a* and *b*. Diagonal slits *c c*, open a communication between the steam-ports and the interior of the steam-jacket. In the position shown in the figure it is evident that the steam admitted at *o* is passing through the lower set of diagonal slits into the steam passage *b*, whilst the steam in the upper part of the cylinder is passing from the passage *a a* through the upper series of slits, and out at the end of the steam jacket. If the valves be moved up past the diagonal slits, the direction of the steam will be reversed.

In some instances two sets of valves are used, one for the steam and one for the exhaust, and in this arrangement the ports at top and bottom are worked by distinct slides, four slides being altogether required. These slides consist of flat plates accurately surfaced to fit the port faces, and by having the exhaust and steam slides separate, they may be manipulated independently of each other, which affords great facilities for regulating to a nicety the

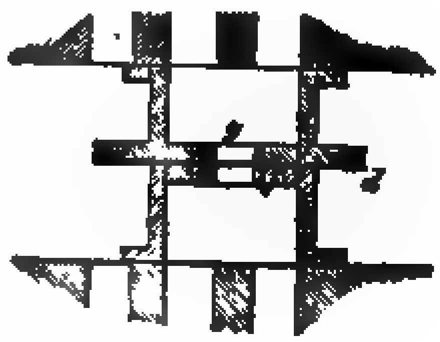
Fig. 59.

admission and exhaustion of the steam. As the steam and exhaust-ports require a somewhat different arrangement, in order that the

pressure of the steam may keep the slides against the faces on which they work, we give two sketches of the arrangement of these slides.

In Fig. 59 the section *e* represents one of the steam slides, and *f* one of the exhaust slides. In the former, *s* is the steam-pipe, *a* the slide, *c* the upper steam passage, and *b* the port face; at *m* the steam pipe is continued to supply the lower valve; as shown, the valve is closed. At *f* the exhaust slide, *c* is the upper exhaust passage, *a* the slide valve, *b* the port face, *x* the exhaust pipe, and *y* a pipe communicating with the lower valve.

Fig. 60.



From these illustrations we see that the valves are so arranged that the greatest pressure upon them is on the side opposite the port face.

Fig. 61.

We will now call attention to some locomotive slides. The slide valves for the two cylinders, shown Fig. 60, are placed on vertical faces in a single steam-chest between the pair of cylinders. One slide has a plate, *d*, cast or bolted on its back, and planed to accurate parallelism with the working face. The other slide has an open box cast upon its back to receive a piston, *f*, having an upper or end face, also planed parallel to the end face. The piston is fitted steam-tight in its cylinder or box, and its planed top bears steam-tight against the face of the plate *d*, in working. By this arrangement the slides are relieved from one half the steam-pressure: and to assist the free exhaust, a port, *g*, is formed in the back plate, *d*, of one of the slides, to allow the steam an additional exit through the exhaust-port of the opposite valve. The other parts of this valve are as usual. Various kinds of valves called equilibrium valves, have from time to time been produced, and one example of the class is

shown in Fig. 61. *a b*, and *c d*, are the steam-passages, *e* the valve, *k k* the steam-chest, *m* the exhaust-pipe. The slide valve works accurately between the port face and the interior of the steam-chest; it is kept steam-tight by packing rings on the surface *f f*, which are pressed against the interior of the steam-chest by springs at the back. All the working faces must of course be accurately surfaced. In the position in which the valve is shown, it is evident that steam is entering the upper steam-passage and leaving the lower one, passing straight through the valve into the exhaust-pipe *m*. On raising the valve the direction of the steam will be reversed. This valve is evidently in equilibrio, as the steam-pressure affecting it equally in both directions, will not exert any action upon it.

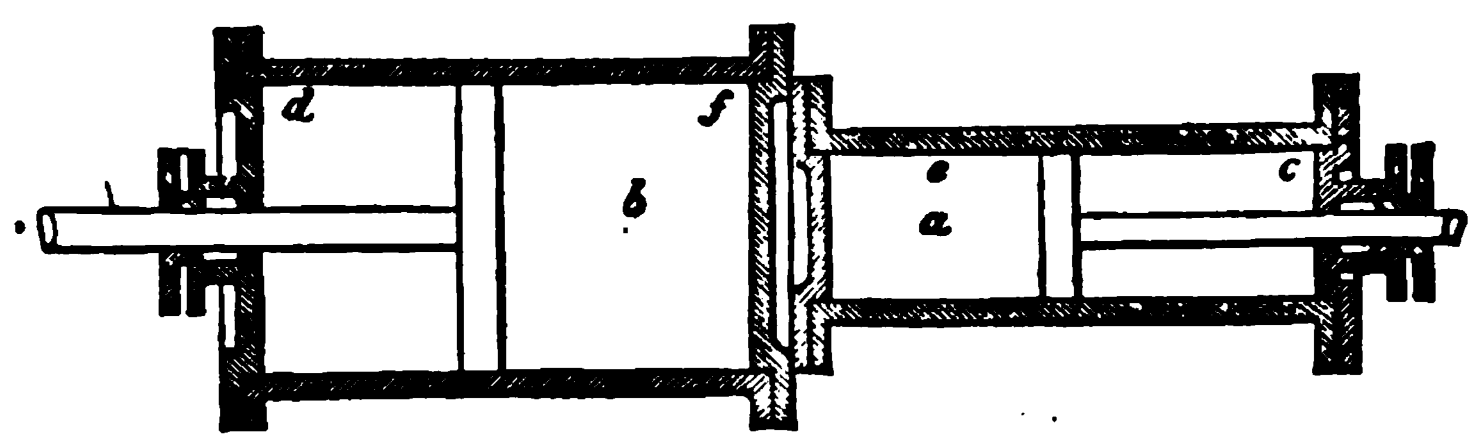
Fig. 62.

There is another kind of equilibrium valve which, although derived from the common short valve, is in principle almost identical with the long D valve. A section of it is shown, Fig. 62. *a* and *b* are the steam passages, *c* the valve, having a cavity corresponding to that of the short slide, but having at its back a semi-cylindrical tube, packed to fit the steam-chest perfectly tight. In this valve the steam, when being admitted to the upper port, passes direct from the steam-pipe *s* to that port, while the steam from the lower end of the cylinder passes out through the cavity *c* of the valve. When the valve rises, the steam traverses its length and passes into the bottom port; the steam in the upper part of the cylinder then exhausting through the cavity *c*. *e* is a plan of the valve, and *f* a section of the same. On the line *c d*.

Before taking leave of the subject of slide valves it will be necessary to pay some attention to those used for double-cylinder engines. And in the first place, the direction of the steam must be carefully observed. It may be best explained by means of a diagram.

In Fig. 63 two cylinders are shown, fitted with pistons, and of these cylinders *a* is much smaller than *b*. It is evident that if high-pressure staem be used in *a*, and after one stroke of the piston has been made, a communication be opened with one extremity of the large cylinder, the steam will pass out of the small cylinder into the large one, because it may thereby expand, and in so doing it will impel the piston in the large cylinder. The advantage

Fig. 63.

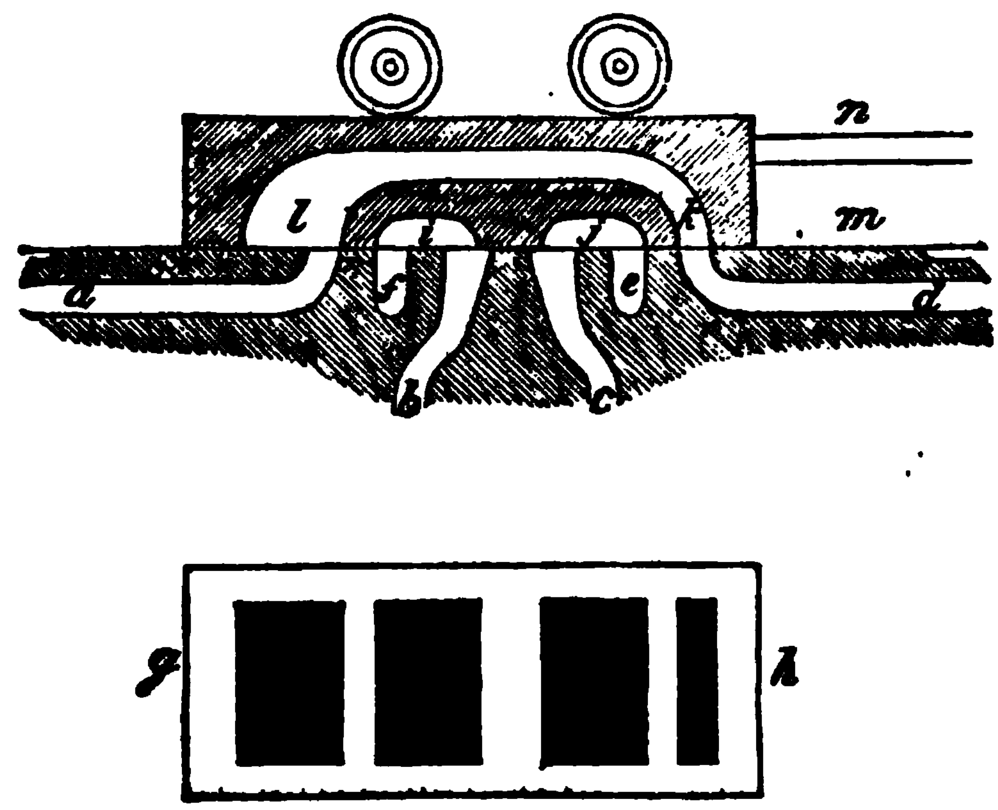



gained is this: that after the steam has done all the work of which it is capable in the small cylinder, it does work in the large cylinder, equivalent to the traverse of the large piston multiplied by the mean pressure in the large cylinder, and by the difference between the areas of the two pistons.

Let it be required to construct port faces and a valve of such form that the steam may run as follows:—first, *say*, into the upper part of the small cylinder, that is to say, into the front end *c*, thence into the end *d* of the large cylinder, and finally from thence into the exhaust. Then the steam which passes into the end *e* of the small cylinder, will pass thence into the end *f* of the large one, and thence into the exhaust. The valve arrangement required is shown (Fig. 64): *a* and *b* are the ports to the large cylinder, *c* and *d* those to the small one, *e* the steam-port, and *f* the exhaust-port. The valve consists of a rectangular block of metal, kept upon the port faces by rollers acted upon by springs, and in this rectangular block or valve certain recesses and passages are cut or cast; *i* and *j* are recesses similar to those in small slide valves, and *k l* is a long passage similar to that in the long valve. In the position shown in the figure, the movement of the steam is as follows. From the steam-port *e* the steam is passing through the recess *j* into the lower port *c* of the small cylinder; the steam in the upper port of the small cylinder is passing from the port *d*, through the

long passage *k l* into the front part of the large cylinder, and the steam in the lower part of the same is passing from the port *b*, through the recess *i*, into the exhaust-port *f*. If the slide be now moved forward the steam will then pass from the steam-port *e* through the recess *j*, into the port *d*; from the port *c*, through *i*,

Fig. 64.




into the port *b*, and from the port *a* into the extremity *l* of the long passage and out at the exhaust *f*. It cannot pass out at the end *k* of the passage, as that will be closed by contact with the part *m* of the port face. *n* is the slide rod; *g h* is a front view of the slide valve. There are many varieties of slides for double-cylinder engines, some of which exhibit great ingenuity, but the foregoing example may be regarded as a type of most of them, wherefore we shall now take leave of this subject.

The next part of the cylinder apparatus which strikes the observer's eye, is, when such is used, the expansive valve; the object of which is to supply a means of cutting off the steam from the cylinder at any part of the stroke of the piston, independently of the action of the slide valve. These valves are usually of simple construction, and Fig. 65 exhibits a section of one form of expansion valve. Let *a b* be the slide-valve jacket or steam chest within which the slide valve performs its usual duty. The steam is not admitted direct to this chest, but to another one, *c d*, placed at the back of it. *e f* is a flat plate of metal, accurately surfaced and fitted to the back of the slide jacket, in which three, or more

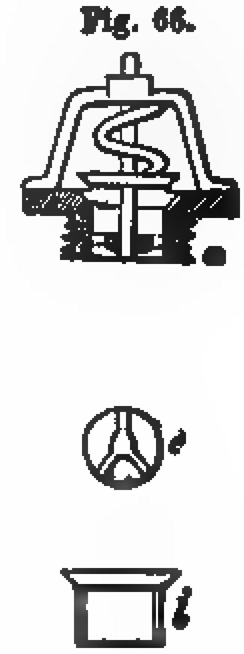
or less, as the case may be, longitudinal slits are made, an equal number of slits being made in the plate $e f$, and so disposed that in one position they coincide with the ports in the back of the slide jacket. It is evident that while the expansion valve, as it is called ($e f$), is in the one position mentioned above, steam will be freely admitted to the cylinder; but a slight movement will cut it off, and the narrower the slits the more suddenly may the steam communication be closed. This motion is imparted to the valve sometimes by an eccentric, but more generally by a cam, as will hereafter be explained. When the slits are very numerous the valve is called a gridiron valve.

Fig. 65.

c

While on the subject of sliding valves, we may mention that all the flat surfaces must be truly planed and scraped, after which operation they will present a mottled or patchy appearance, being a very near approach to a true plane, but consisting in reality of small irregular hollows and ridges. When the surface is planed only, it consists of numerous grooves and furrows; but approaches most nearly to an accurate plane when it is truly ground with very fine grounding powder, the operation, however, being so inconvenient that it is not practised for flat work. After the slides have been in use for some time, they present on their surfaces a bright appearance, exercising also a chromatic effect probably due to thin layers of oxide on the surface of the metal polished by friction. In fitting up the valves great care must be taken that, when finally set in position they are perfectly free from any kind of grit or dirt, otherwise the faces will be injured.

Fig. 66.

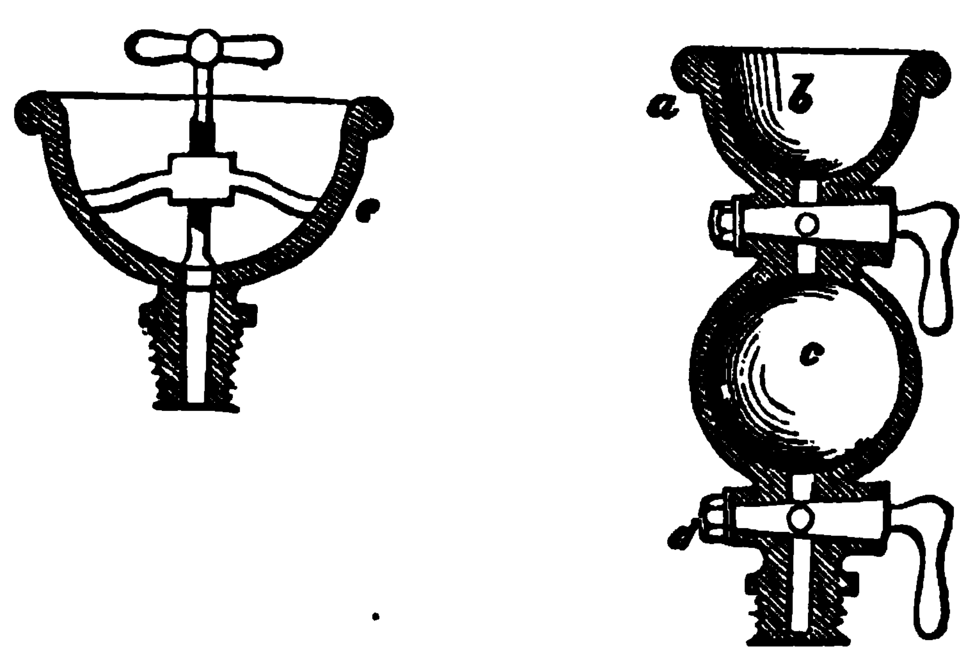


It sometimes occurs that water collects in the cylinder, and as it cannot be readily expelled through the ports, it is necessary to provide some special means of exit. For this purpose a valve of the form shown (Fig. 66) is frequently used. It consists of a plain

conical valve, with a spindle working in guides or with a stalk. It is kept in its seat by the action of a spring. The apparatus may be screwed into the cylinder cover, or otherwise be made to communicate with it. If any water accumulate in the cylinder, the piston will, at the termination of its stroke, force it out through the valve. *a* represents a section of a valve and seat, suited to be screwed on to a cylinder cover. The valve is furnished with a spindle moving in guides. *b* and *c* exhibit an elevation and bottom plan of a stalk valve removed from its seating.

There is yet another kind of fitting which demands our attention in connection with the cylinder; it is a grease-cock, the object being to supply lubricating material to the internal parts of the apparatus while it is at work. We show at Fig. 67 sections of two forms of grease-cock, both intended to be screwed into the cylinder or other part where they may be required. In the sec-

Fig. 67.




tion *a* the lubricating material is poured into the cup *b*, then by turning the stop-cock between *b* and *c*, the grease flows into the reservoir *c*. This cock is then closed, and the lower one opened, when the grease will flow into the vessel to be lubricated. At *e* is shown a class of grease-cock suitable for low pressure or condensing engines. The cup is closed at the bottom with a valve, capable of being raised by a screw on turning the handle shown in the section. The method of using it is as follows: when the piston is receding from the grease-cock, and there is consequently a vacuum formed beneath the latter, the valve is opened, upon which

the pressure of the atmosphere forces a portion of the lubricating material into the cylinder.

The cylinder is fitted also with a cock for blowing the steam through both ends at once.

Now that we have described the form and construction of the cylinder, and those parts which are attached to it, we will pass on to the next class of general elements.

# CHAPTER XIII.

## ON THE DETAILS OF STEAM-ENGINES—(*Continued*).

### *Pistons, Rods, Beams, Governors, &c., &c.*

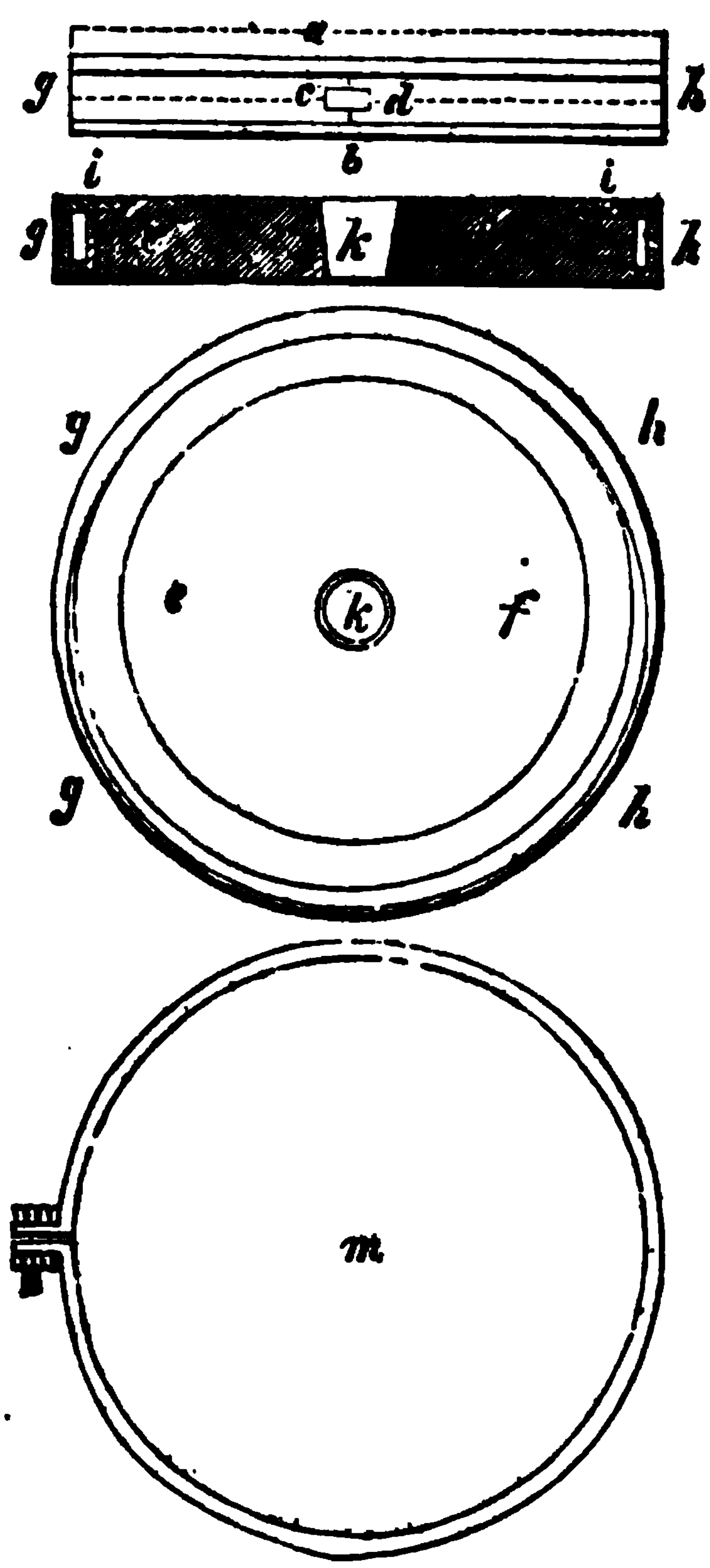
THE steam-cylinder having been fully discussed, with its external appendages, it is necessary to examine its interior mechanism; the first and most important part of which is the piston, upon which the steam acts directly, and to which it communicates its energy. It is evidently very necessary to exercise much care and ingenuity in order to obtain a satisfactory result; the requirements being that the piston shall fit the cylinder as nearly as possible air and steam-tight, that it shall be as durable as possible, and move with the least possible amount of friction. With the metallic packing now exclusively used, results in practice very satisfactory, fulfilling as nearly as possible the above requirements, have been arrived at, the leakage being equal to an aperture about the five-thousandth of an inch in width.

It is advisable to commence the description with the simplest form of piston, observing, however, previously, that the aperture in the centre of the piston is intended to receive the piston rod.

Fig. 68, *a b*, and the following sketches, show views of a simple form of piston. The first view is an elevation, the second a section, and the third a plan. *a b* are the top and bottom surfaces of the piston, *g h* a cut packing ring, *c d* a tongue piece, to prevent the leakage of steam where the packing ring is cut through; *e f* in the section and plan show the body of the piston, *i j* the junk ring, and the aperture for the extremity of the piston rod. The junk ring has for its office to hold the packing ring in position, and it is attached to the body of the piston by means of bolts. The plan is taken with the junk ring removed, in order to show the packing ring in plan. It will be observed that this packing

ring is not concentric, that is to say, it is not of equal thickness throughout, being made thinnest at the point where it is cut through, and increasing in thickness both ways to a point diametrically opposite, the object being that the packing ring may press equally upon the cylinder at every part of its periphery. This ring is usually made of cast-iron, which exhibits a very uniform elasticity. The description of the piston being completed, it is necessary to explain the method of manufacturing it.

Fig. 68.




The first step should consist in boring out the aperture $k$, after which a rod may be fitted into it; then the piston is, by means of this rod, suspended between the lathe centres, and its body is accurately turned, and drilled and tapped to receive the junk ring bolts. The upper surface of the flange of the piston being scraped

and faced to fit the packing ring, and the lower surface of the junk ring being treated in a similar manner, the upper and lower edges of the tongue piece are also fitted by scraping to the surfaces with which they are in contact. There are two ways of making the packing ring; it may be turned in the lathe to a diameter a little greater than that of the cylinder, when the following means will be required to introduce it into the same. An iron hoop, cut on one side and furnished with lugs, as shown at *m*, is placed around the piston so as to embrace about half the depth of the packing ring, as shown by the dotted lines at *g h*. It is then screwed up by means of the bolt and nut shown at *n*, until the packing ring is sufficiently compressed to partly enter the cylinder; the ring *m* may then be removed, as it is evident that the cylinder embracing the packing ring will effectually prevent its expansion. The piston may then be forced completely into the cylinder. A method used occasionally, consists in turning the ring accurately to the diameter of the cylinder, then hammering it on the internal periphery, to render it hard and elastic, and to impart to it a sufficient degree of tension, so that when it is subsequently cut, it may expand and press against the sides of the cylinder. This ring must of course be inserted in the same manner as the last.

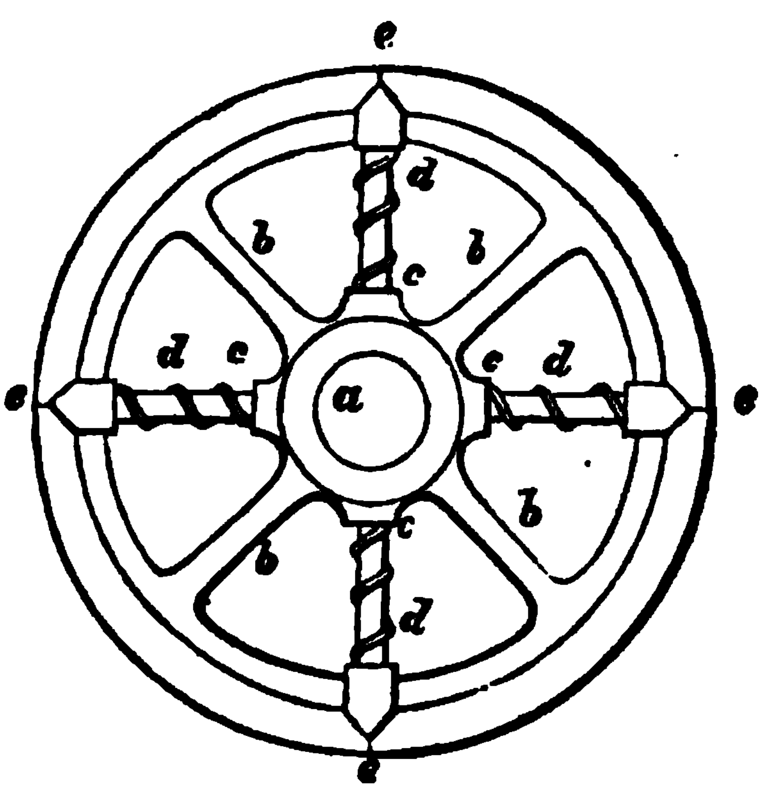
The above may be considered a general description of the most ordinary kind of piston. It will be necessary next to describe some varieties of steam-pistons. The first approaches very nearly in principle to that already described; it is furnished with a cut ring precisely similar to that already described, but this ring does not press immediately upon the internal surface of the cylinder, but it acts upon rings external to it, which are thus urged against the interior of the cylinder. These outer rings are usually made in three or more segments, so as to adapt themselves as nearly as possible to the form and variations of form of the cylinder. In the construction of this piston, the method followed is similar to that already detailed, which may, in fact, be regarded as the general method of constructing steam-pistons, the modifications in each case being obvious.

Large pistons are not constructed with solid bodies, but they are hollowed out, presenting in horizontal section the appearance of a wheel, as it consists of a boss through which the extremity of the piston rod passes, which boss is connected with the periphery

of the piston by means of plates, top and bottom, and arms which run from the boss to the periphery.

Among the means which have from time to time been proposed for packing pistons, the action of a great variety has been made to depend upon the action of spiral springs, which press outwards from the boss of the piston to the periphery; in the form these springs are caused to act upon wedges, which being urged outwards, tend to force apart the segments. The accompanying Fig. 69, will give some idea of the arrangement of a piston upon

Fig. 69.




this principle: *a* is the aperture in the boss of the piston, through which the extremity of the piston rod passes, and in which it is secured. This boss is connected with the periphery of the piston, and with the bottom of the same by the arms *b b; c c c c* are four stops, against which the extremities of the spiral springs abut; the springs *d d d d* are guided by rods passing through their axes for a portion of their length; the springs act upon wedges *e e e e*, which, in being pressed outwards, necessarily tend to separate the four segments into which the external packing ring is divided. This piston has not come into general use, being attended with many disadvantages, one of which is to wear the cylinder irregularly. They are also inconvenient on account of their complicated form.

Pistons are not unfrequently packed with large out rings, or segments, which are urged against the cylinder by small blade-springs, placed between the body of the piston and the packing

ring. In some cases, these springs have been supported by arms proceeding from the centre of the piston instead of abutting against the periphery, which periphery is, in the present case, dispensed with. The arrangement of this piston is the shown Fig. 70; *a* is, as before, the aperture for the piston-rod, *b c d* a cut packing ring, *e e e e* four arms, which serve a double purpose, connecting the boss with the top and bottom of the piston, and carrying at their extremities the blade-springs *f f f f*. These springs press outwards against the cut ring *a b c*, which is cut at *b*; these springs may, by set screws, be adjusted to exert any required pressure upon the packing ring. This arrangement appears, however, too fanciful for practical purposes, and it has not come into general use.

Another form of piston has been proposed, which is shown, Fig. 71. This is furnished with a cut ring; *a* is the aperture for

Fig. 70.

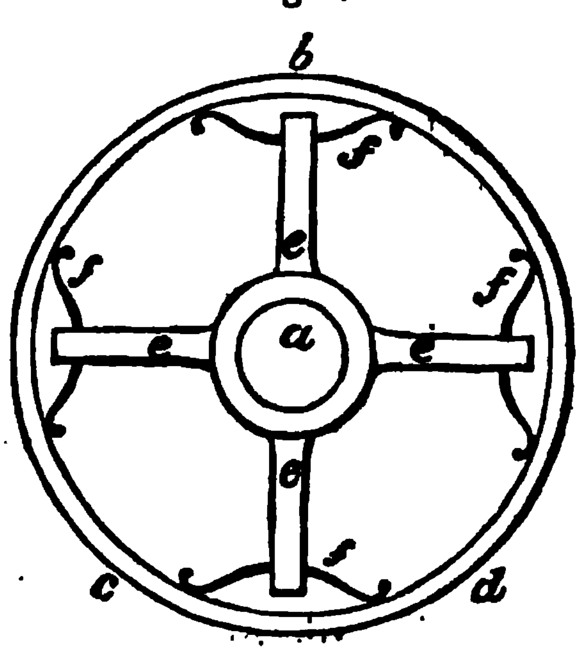
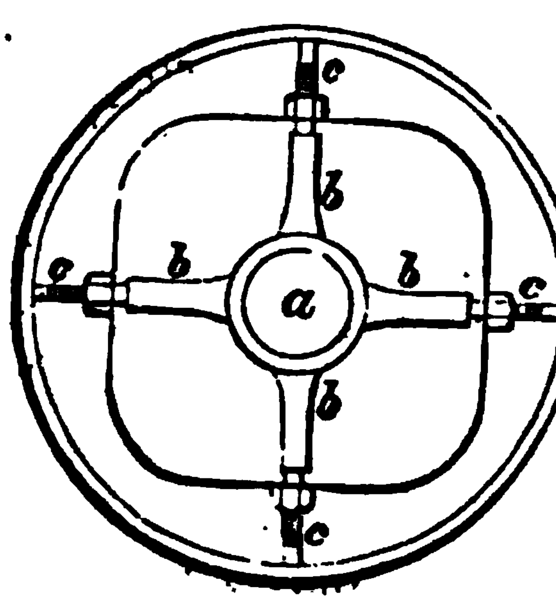



Fig. 71.




the piston rod, *b b b b* are arms, *c c c c* is an elastic ring, which is distorted, as shown by the set screws, which set screws working in nuts attached to the ring, abut at their farther extremities upon the cut ring, and as the distorted elastic ring tends to regain its circular form, the set screws are pressed against the packing ring. This piston, like the previous one, possesses the disadvantage of being complicated.

In another form of piston, an elastic ring is also used, but in this case it is compressed by one set screw only. None of these forms, however, have, as yet, superseded the first piston which we described.

Before taking leave of the subject of steam-pistons, we must call the reader's attention to the section shown, Fig. 72: *a b c* are

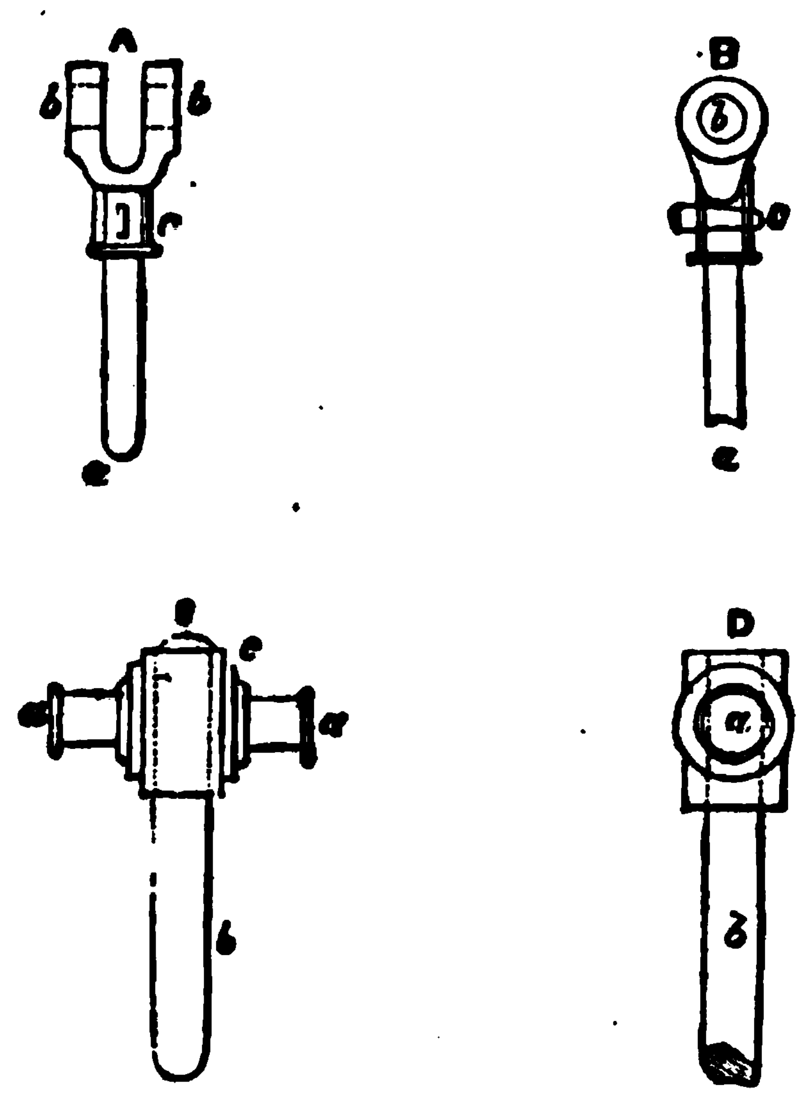
three cut rings, precisely similar in their mode of action to the ordinary ring described at the commencement of the chapter, *d* is

Fig. 72.

the aperture in which the piston rod is fixed, *e e* show the general body of the piston; the packing rings are made very narrow, about a quarter of an inch wide, several of them being used. These rings are each placed in a separate groove. This piston is certainly the most simple in construction that we have yet seen; it has been applied with considerable success to locomotive engines.

The next element to be considered is the piston rod, which, however, from the extreme simplicity of its form, will require but a short notice; it is usually made of wrought-iron, and accurately turned in the lathe. To the top of this piston rod various kinds

Fig. 73.



of cross-heads are attached, according to the class of engine for which it is designed.

To calculate the diameter of the piston rod, we have the follow-

ing formula. Let $p$ be the maximum pressure of steam per square inch, $d$, diameter of cylinder in inches, D, diameter of piston rod in inches; then

$$D = \frac{d}{55}\sqrt{p}$$

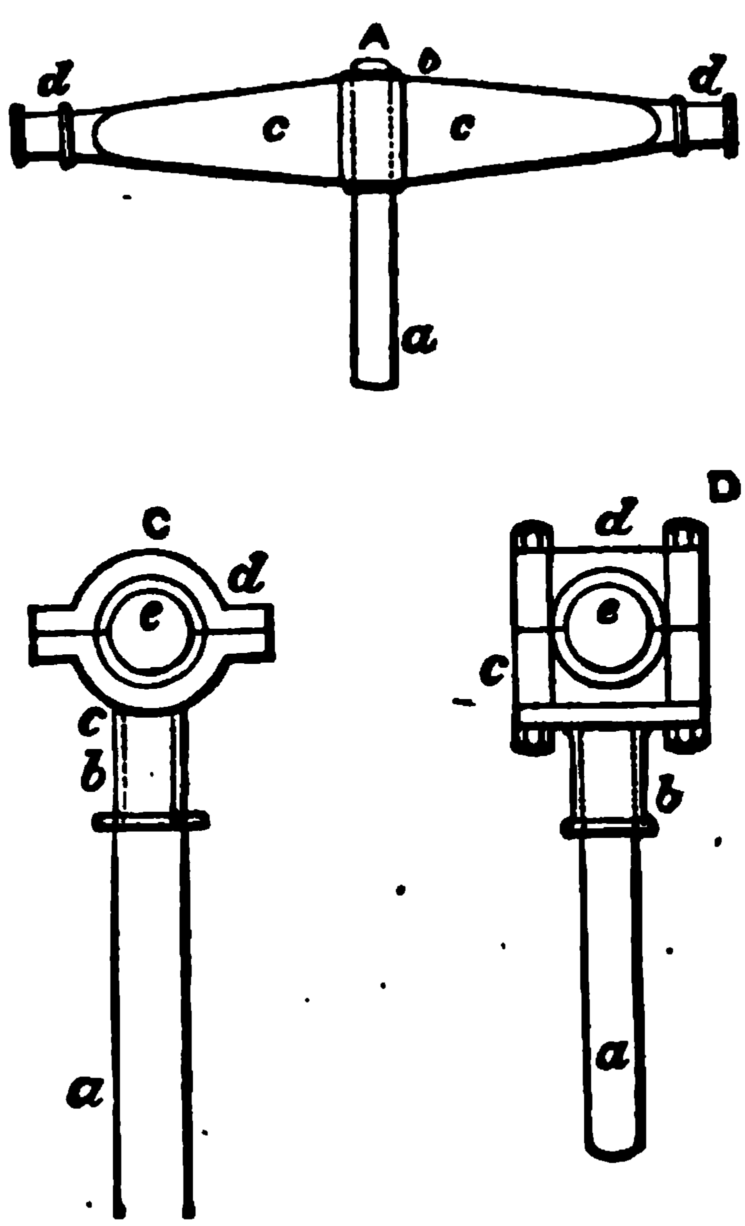
For low-pressure engines, where the total pressure does not exceed 30 lbs. per square inch, the diameter of the piston rod may be made equal to one-tenth that of the cylinder.

It now remains to describe the various kinds of cross-heads commonly used with the piston rods of steam-engines. Some of these are shown in Fig. 73. A B are elevations of a cross-head commonly used when the piston rod is immediately jointed to the connecting rod. In the sketches, *a* shows the extremity of the piston rod, which is passed into the tubular part, *c*, of the cross-head, where it is firmly fixed; above this, the cross-head is forked, in order to admit the extremity of the connecting rod, and the forked ends have cylindrical apertures, *b*, bored through them to receive the pin, which joins the piston rod to the connecting rod. C and D are elevations of a cross-head used with beam engines; the part *c* is perforated and traversed by the extremity of the piston rod, *b*; *a a* are gudgeons, which carry the extremities of links connecting the piston rod with the main beam. When no links are used, as in the case of the half-beam engine, either the end of the beam or the cross-head may be forked, a movable pin being used.

At Fig. 74, A is an elevation of a cross-head used for side-lever engines; *a* is the extremity of the piston rod, which is passed into the perforation, *b*, of the cross-head; *c c* are the two arms of the cross-head, and *d d* two gudgeons which carry the extremities of links, which descend to the side levers or beams placed upon each side of the steam-cylinder. C and D show two kinds of cross-heads used when the piston rod is jointed direct on to the crank, as is the case in oscillating engines. *a* is the piston rod, *b* the perforated part of the cross-head *c* and *d*, plummer-block and cap of the cross-head, *e* aperture for crank-pin, which is surrounded by brass bearings as shown. The cross-heads are joined, where necessary, by bolts. The plummer-block and cap of C are frequently made of gun-metal, when no brass bearings will be required.

In the former figure, C is very similar to a kind of cross-head used in some kinds of locomotive and other engines. The square part of the cross-head is provided with small ridges or guides, as shown by the dotted lines, parallel to the piston rod; this block moves between accurately formed guides, and the protruding journals, *a a*, carry the ends of a forked connecting rod. This

Fig. 74.




cross-head is sometimes placed at the extremity of the piston rod, and sometimes elsewhere; the square part is called the guide-block.

The cross-head shown at *a* generally has the connecting-rod pin prolonged, guiding blocks being carried at its extremities, which move between suitable guides.

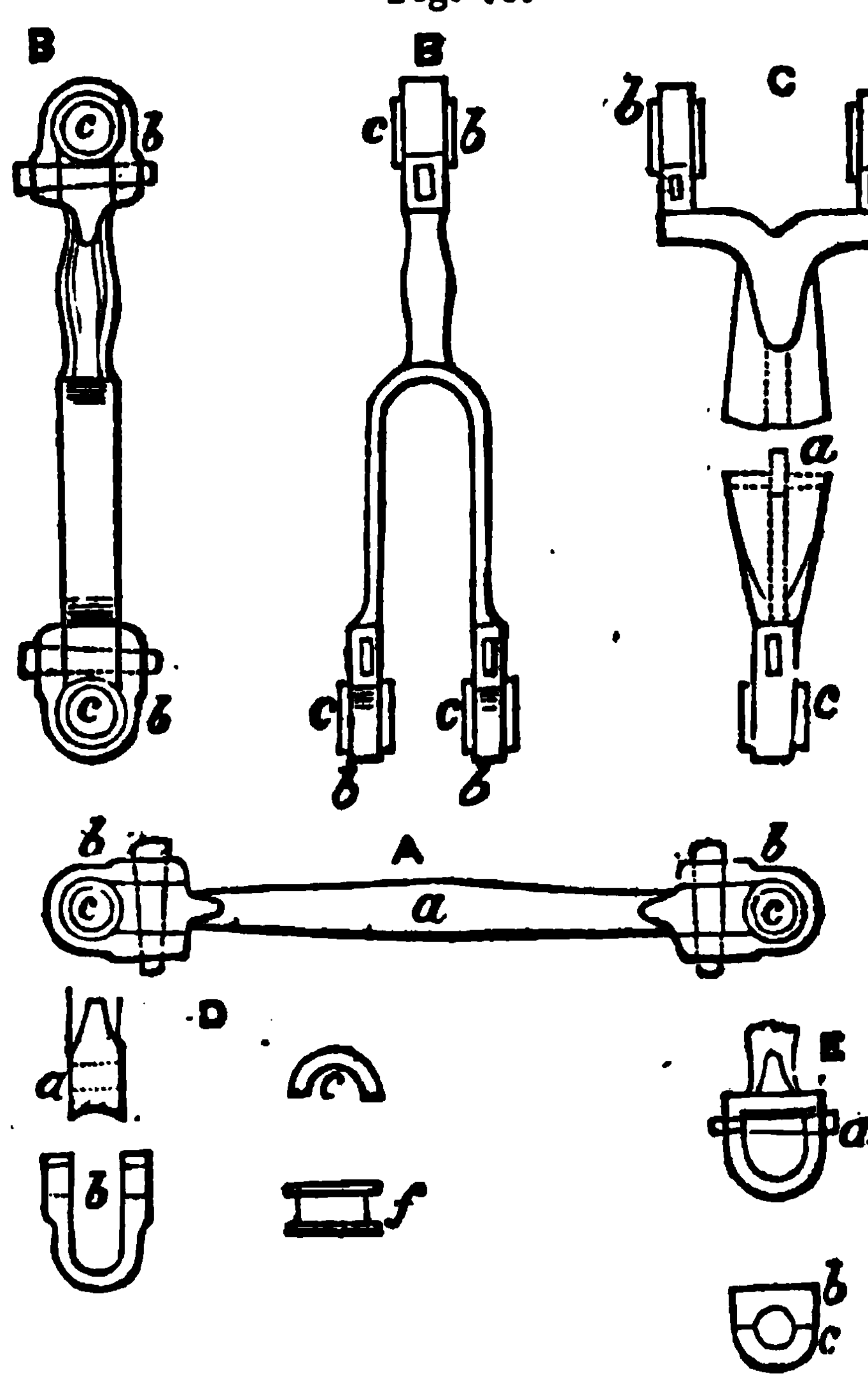
These are the general forms of cross-heads, and with regard to their construction, we may make the following brief remarks. Whenever it is convenient, they should be of wrought-iron, and all the round parts must be turned, the flat ones planed, and the bearings, whether sliding or revolving, accurately fitted to each other, by scraping in the usual manner. Those parts which are

of irregular form must be brought up to a bright surface, by means of files of suitable forms.

Having completed the descriptions of cross-heads, connecting rods and parallel-motion links will next occupy our attention. We will first describe the former class of elements.

A, Fig. 75, shows a form of connecting rod, commonly used for engines, where the piston rod is joined on to the connecting rod; it consists of a spindle *a*, having at each end bearings *b b*, retained in position by straps fixed by wedges and keys passing through them, and through the extremities of the spindle. Of these straps and bearings we will, however, speak subsequently. B shows a connecting rod of the forked description, as used with the single guide-block. This is also furnished with bearings similar to those last described.

Fig. 75.



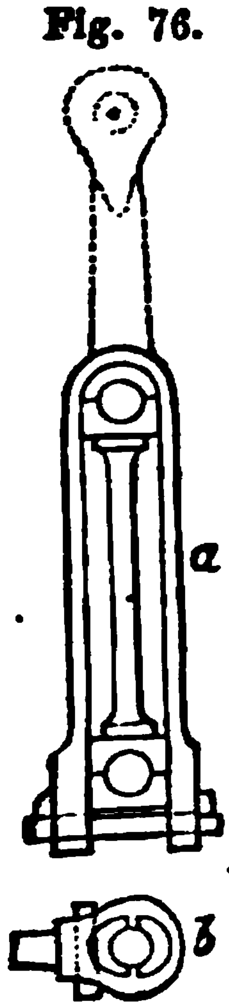

C shows an elevation of a connecting rod, frequently used for beam engines; it is broken off to save length, the upper and lower

extremities only being shown. *a* is a round spindle for wrought-iron, but of an × section as shown, by the dotted lines for cast-iron. At *b b* are two bearings, similar to those already mentioned, which embrace the journals of a pin in the mainbeam; *c* is the crank-pin bearing, and is of peculiar form, presently to be described. D shows bearings of the first class, *a* being the end of the connecting rod, *b* the straps, *c f* elevation and plan of brass bearings. E shows the second kind of bearing as mentioned in connection with the beam-engine connecting rod; *a* is the extremity of the connecting rod, into which bearings *b* and *c* are placed, after which they are passed over the crank pin, and tightened up by the wedge dotted at *a*.

With regard to the construction of connecting rods, there is but little to be said. Wrought-iron is the best material to use for their formation. The parts may be wrought in the same manner as that described for the cross-heads; all the bearings should be of brass or gun-metal, and must be accurately fitted to the gudgeons on which they play. The method of connecting them to the other elements will be mentioned hereafter.

We have now to consider the construction of links for parallel motions, &c. Many of them are precisely similar in general form to those already described; some have, however, different forms, as shown, Fig. 76. *a* may be said to consist of a long strap, into which two sets of bearings, furnished with ridges to guide them, are placed and keyed up tight, being retained at their proper distances by means of a strut or distance piece, as shown. *b* shows the extremity of a link which is bored out at the end larger than the bearings which are inserted, placed around the journal, on which they are intended to work, and keyed up tight.

Fig. 76.




The construction of links is identical in its details with that of connecting rods. Before concluding the subject, it may be desirable to mention the fact, that links requiring three bearings are frequently made as a combination of the two forms illustrated above, the complete link being surmounted by a bearing extremity, as shown by the dotted lines.

The next subject to be mentioned, consists of parallel motions,

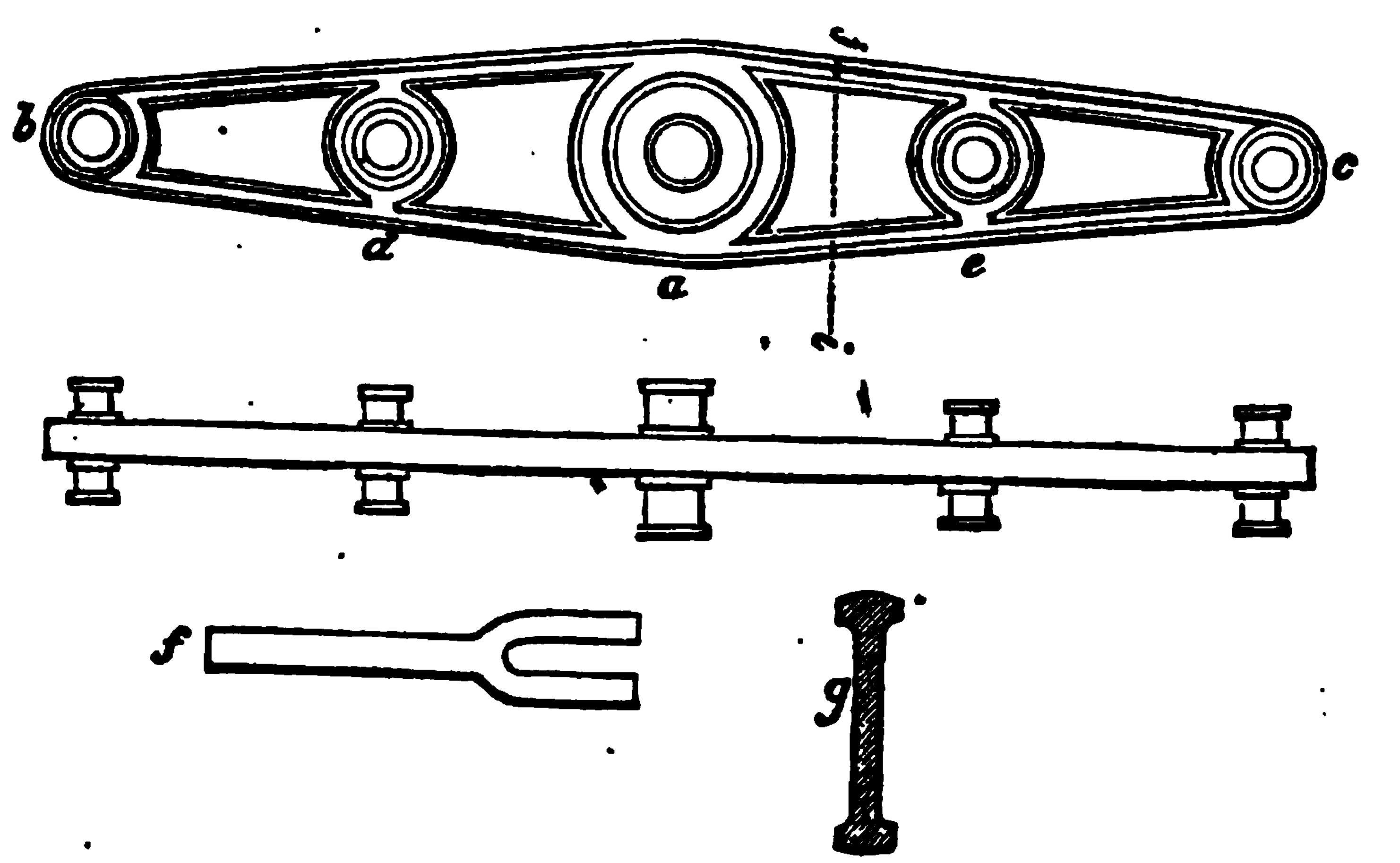
one class of which consists of elements already described, another also has been mentioned, which consists merely of guides between which slide-blocks move in a rectilineal direction, having a reciprocating motion.

Another method, which is attended by results of a very satisfactory character, consists in prolonging the piston rod beyond the cross-head, and carrying its extremity in a piece of metal, bored out cylindrically to such a diameter as to allow it to move freely within it. When this method is employed, the piston rod should be made somewhat stronger than usual, as it will then have to sustain the stress due to the varying angularity of the connecting rod.

The beam next requires attention. It is an element simple in its form, and will require but little description. An elevation of an ordinary beam is shown Fig. 77. *a* is a gudgeon, upon which the beam is supported; *b* that to which the piston rod is attached; *c* that carrying the connecting rod; *d* and *e* are other gudgeons, which serve for the support of pump rods, &c. Beneath the elevation is shown a plan of the beam.

This beam will be used with a forked connecting rod, &c.; but at *f* is shown a plan of the end of a forked beam, such as is used

Fig. 77.




in side lever and grasshopper engines. At *g* is shown a section of the beam, taken through *i j*.

The proportions generally adopted where no special circumstances prevent their employment, are, for the various elements now described, as follows:—

The stroke of the piston should be twice the diameter of the cylinder to get the least cooling surface of steam-cylinder. The beam should be three times the length of the stroke, and its depth at centre should be equal to the diameter of the cylinder. The connecting rod should be from twice to thrice the length of the stroke.

The rule to calculate the thickness of the beam at the centre will be as follows:—

Let $p$ = maximum pressure per square inch on the piston, $D$ = diameter of cylinder in inches, $d$ = depth of beam in inches, $l$ = length of half beam in feet, $t$ = thickness in inches. Then

$$t = 0.02, p\, l \left\{ \frac{D}{d} \right\}^2$$

but if the foregoing proportions be used,

$$D = d$$

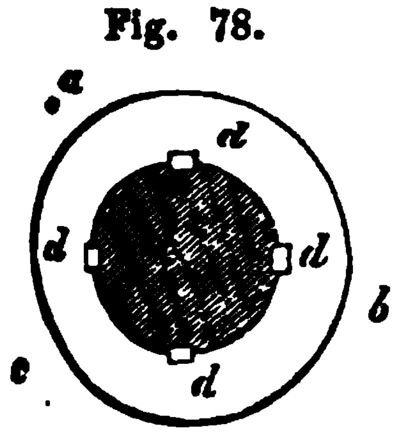
hence

$$t = 0{\cdot}02\, p\, l$$

The method of applying this calculation to half beams is obvious for we have only to take for the value of $l$ the distance between the centres of the gudgeon, which carries the top of the piston rod, and that by which the connecting rod is carried.

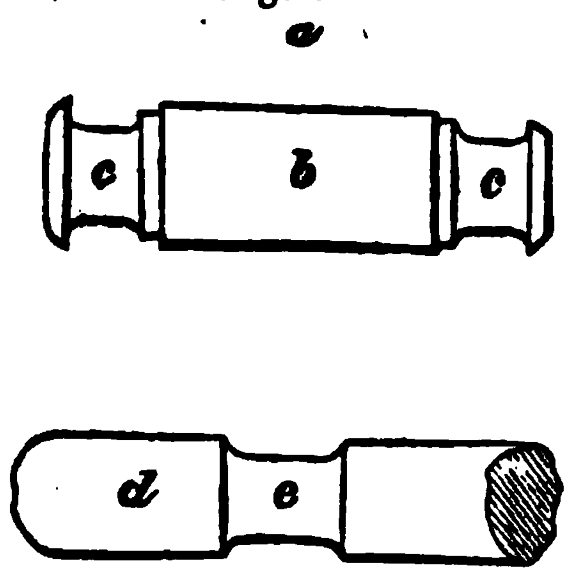
The beam is usually made of cast-iron, and the manipulations to which it is subject after leaving the foundry are not of a very extensive character, for all that remains to be done consists in boring the apertures to receive the gudgeons, and fitting the latter to the beam. A favorable opportunity now offers itself to consider the means employed for fixing cylindrical elements to cylindrical apertures, when it is necessary that they be incapable of movement. Fig. 78 shows a section of shaft upon which it is required to fix a cylindrical band or boss immovably; $e$ is the shaft, and $a\ b\ c$ is the boss. It is bored to fit with accuracy the shaft which has been previously turned, and in both the boss and the shaft certain slots are made to admit keys $d\ d\ d\ d$, which keys prevent the shaft from revolving within the boss. The method now described is that generally used for fixing the gudgeons of beam engines. There are other methods of fixing bosses upon shafts, but these will subsequently be mentioned.

Fig. 78.



The form of these pins or gudgeons, and in fact of journals generally, now requires attention. In Fig. 79 *a* represents an elevation of a gudgeon for a beam. The central part *b* does not in every case require to be turned; but the journals *c c* must be accurately brought to the required form; *d* represents the general form of journals. The part *e* must be accurately turned, as it will work in contact with the bearings. The other parts of the shaft are also turned, although accuracy of form is not necessary on the general surface.

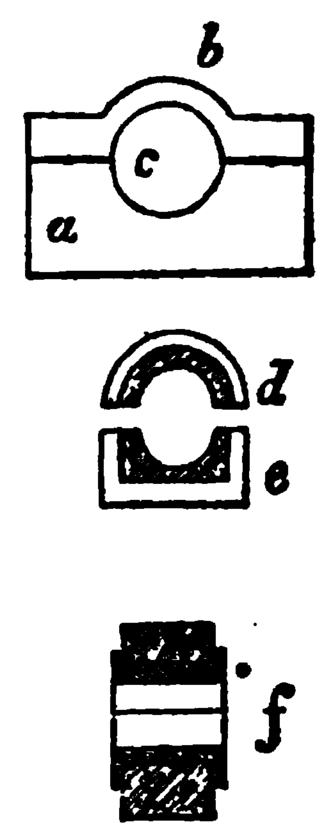
Fig. 79.




The next matter to be considered is the form of bearings generally, and these are shown in Fig. 80.

*a* is a solid block of cast-iron, having on its upper side a rectangular notch or recess: it is called a plummer block. This is surmounted by a cast-iron cap *b*, having in its lower surface a semicircular notch. The two are connected by bolts, as shown. The general form of this arrangement will at once be recognized from the general resemblance which it bears to some forms of piston-rod cross-heads. Between the plummer block and cap, brass or gun-metal bearings are placed, of which sections are shown at *d* and *e*, *e* is first placed in the plummer block, *d* is placed upon it, and then the cap *b* is bolted down to the plummer block. The bearings are furnished with flanges, to prevent their sliding away from their proper position. At *f* is shown a vertical section through the plummer blocks and bearings, which shows the general arrangement. The bearings are usually bored out accurately, and subsequently fitted to the journals, which they are intended to sustain, by scraping.

Fig. 80.

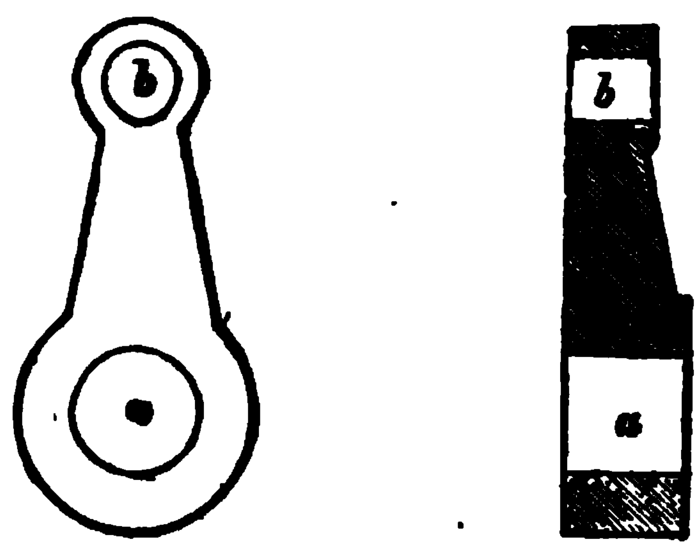



Various forms of plummer blocks and bearings are used, but the one described will convey a general idea of the principle involved in their construction.

Next to the beam comes the connecting rod; but the various forms of this element have already been considered.

The crank now requires attention, with regard to general form and construction; the theory of its action having been already treated. Fig. 81 shows the general form of one class of cranks, viz., those which are not made in the piece with the crank shaft. It is desirable to use this form whenever it is available for small engines. Cast-iron cranks are not unfrequently used, but wrought-iron is certainly preferable, and no other material should be allowed

Fig. 81.




in the construction of engines of considerable size. Cranks for inferior purposes are very frequently made by bending the crank shaft to the required form; but this method does not yield results of so satisfactory a character as that which consists in forging upon the crank shaft a solid projection, and subsequently cutting out the aperture of the crank.

When separate cranks are used they must be planed on the surfaces, and then bored accurately to receive the shaft and the crank pin. In the figure, *a* shows the aperture for the shaft, and *b* that for the crank pin. In fixing cranks upon the crank shaft, keys will be found advantageous; but it is also advisable to employ the method known as shrinking on, which consists in heating the crank boss until it will just pass into its position, having been originally bored out to a diameter somewhat less than that of the shaft on which it is to be fixed. Then it is placed upon the shaft in the required position, and allowed to cool, whereupon it takes a firm grip of the shaft.

The next element to which the reader's attention will be called is the crank shaft or main shaft of the engine, and the first step towards the construction of the same will consist in calculating its diameter, which may be effected by the following formula:—

Let $d$ = diameter of shaft in inches.

H = horse-power of engine, calculated for the maximum pressure.

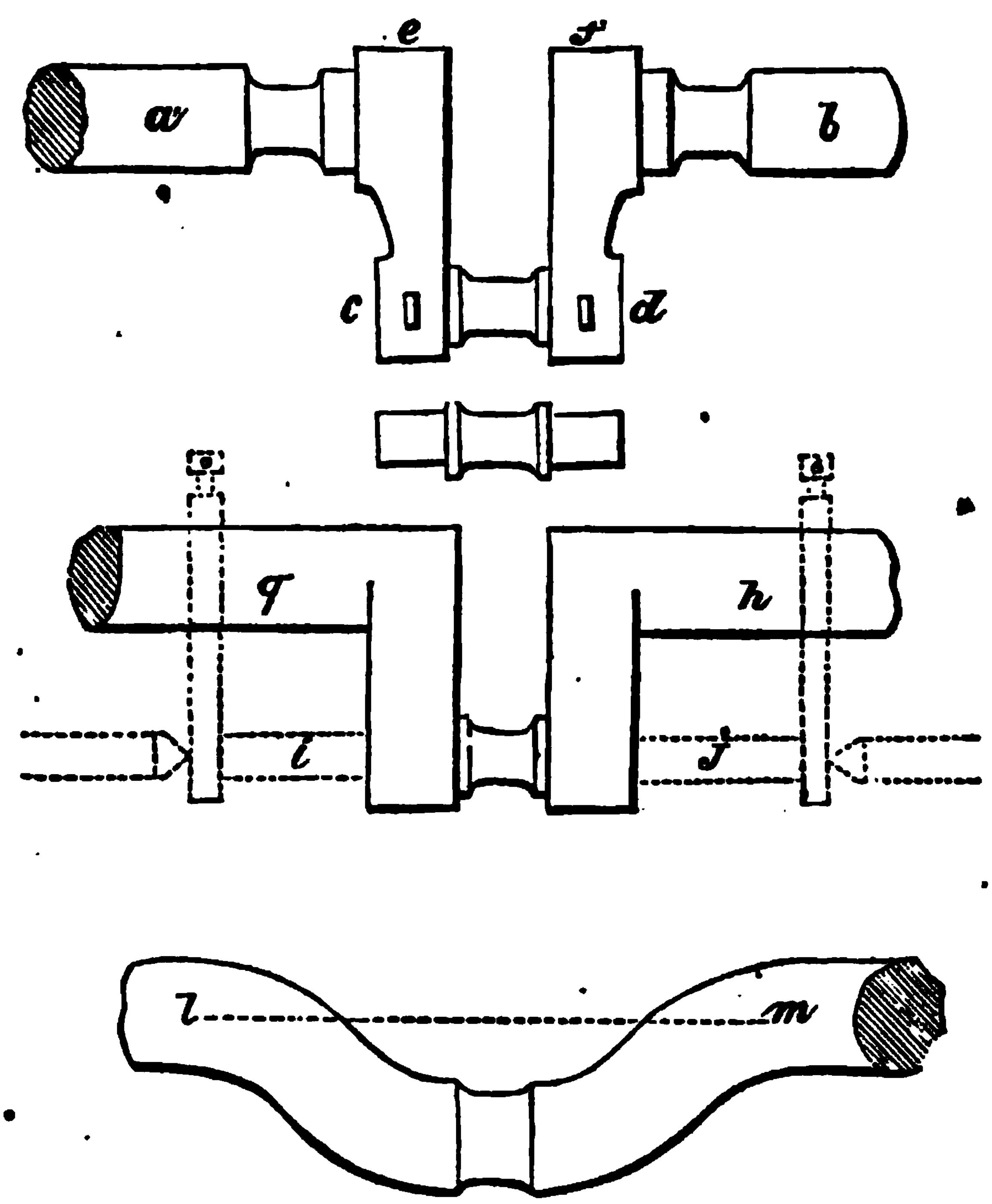
N = number of revolutions per minute performed by the engine.

Then the diameter may be found from the equation—

$$d = \sqrt[3]{\frac{320\ H}{N}}$$

This calculation applies, of course, to the smallest part of the shaft, which will generally be the journal. The general form of

Fig. 82.




the crank shaft may now be described. In Fig. 82 three forms of crank shaft are shown, and the first form will also serve to illustrate another arrangement.

$a\ b$, Fig. 82, shows two portions of a crank shaft, fitted with two cranks, $e\ c\ f\ d$, carrying a crank pin, $c\ d$. Close behind the cranks,

journals are turned upon the shafts, which rest in the shaft bearings. Beneath is shown the form of the crank pin, which may be secured by wedges driven through the small bosses of the cranks. If we conceive the part *d f b* to be removed, then will *a e c* represent the arrangement used in engines having but one crank. *g i j h* represents a crank shaft having the crank forged in one piece with it, and *l m* shows a shaft where the crank is forged upon it; but instead of having vertical arms, as in the last case, they are curved.

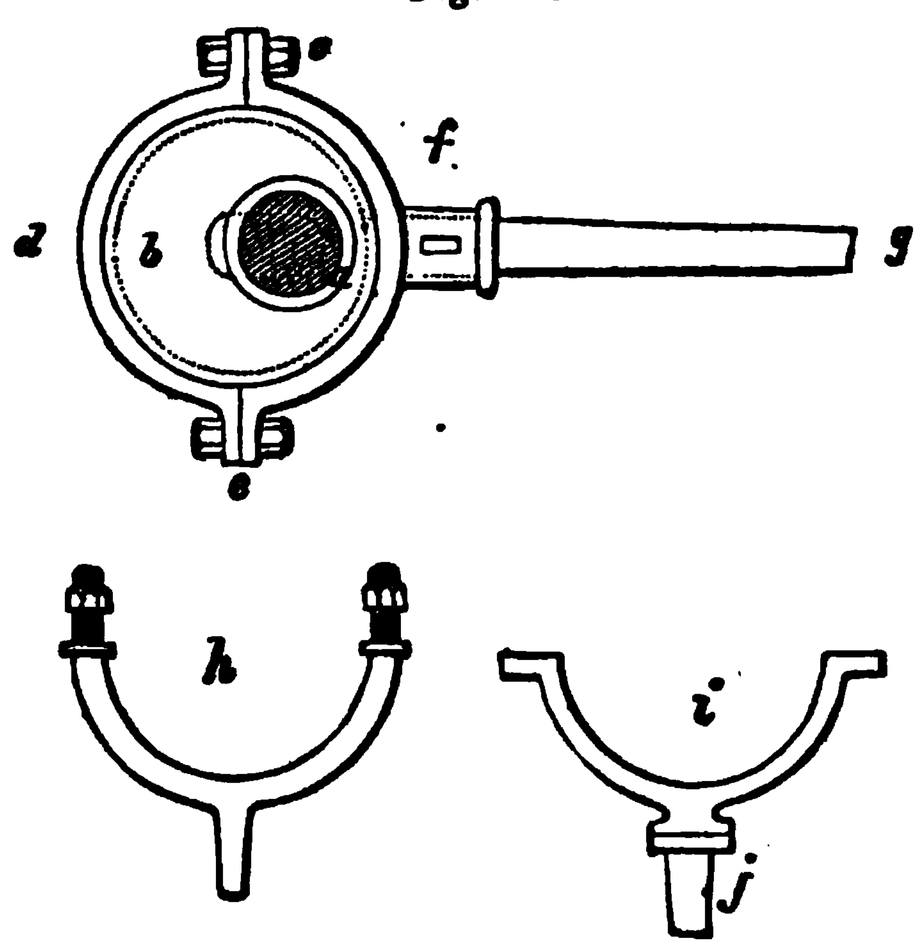
With regard to the construction of the crank-shaft, we may observe that it is usual to bring it up to a bright surface, turning those parts which admit of such treatment, and planing and filing others. In turning the crank-pins in such arrangements as those shown by *g h*, some particular method of centring the shaft must be adopted. The dotted lines at each extremity show carriers, in which centres are made in a line with the axis of the crank-pin, and between these centres the work is supported in the lathe, the carriers being properly blocked to retain them in the proper positions.

The bearings of the crank-shaft are usually of the form already described when treating of those employed for the support of the working beam.

Those elements which are carried by the main shaft will next require attention, and the first which occurs after the crank is generally speaking, the eccentric. This consists of a wheel or pulley of a truly circular form, but fixed upon the shaft eccentrically to it; and it may be supposed to be produced by increasing the dimensions of an ordinary crank-pin until they arrive to such a point as to extend in every direction beyond the main shaft. Fig. 83 illustrates the arrangement of the eccentric; *a* is the main shaft to which the eccentric is keyed; *b* is the eccentric sheave, on the edge of which is a groove to receive a band, within which the eccentric sheave may revolve. This band corresponds with the cross-head of the piston rod when that is jointed directly on to the crank-pin. The band is made in two parts, *c d e* and *e f c*, which are connected with bolts at *c* and *e*. At *f* is a socket to receive the extremity of the eccentric rod, which is firmly keyed therein. This is the arrangement generally used with gun-metal straps. Sometimes, however, it is found expedient to make both sides of the strap of the same form as *c d e*, and in this case the

eccentric rod is forked, as shown at *h*, and the extremity of each fork is screwed after the manner of a bolt, so that the screwed ends, being passed through the bolt-holes at *c* and *e* and furnished with nuts, supply at once the means of connecting the two halves of the strap with each other and with the eccentric rod.

Fig. 83.




It frequently happens that instead of gun-metal straps, others, formed of wrought-iron, are employed, and in this case the eccentric rod may be forged in one piece with the half of the strap. In other cases, however, one half of the strap is made as shown at *i*, the extremity of the connecting rod being of the form shown at *j*, so as to admit of its being bolted to the eccentric strap.

The eccentric rod may be jointed direct on to the slide-valve rod, or on to an arm attached to a shaft carrying another arm, from which a slide-valve is worked.

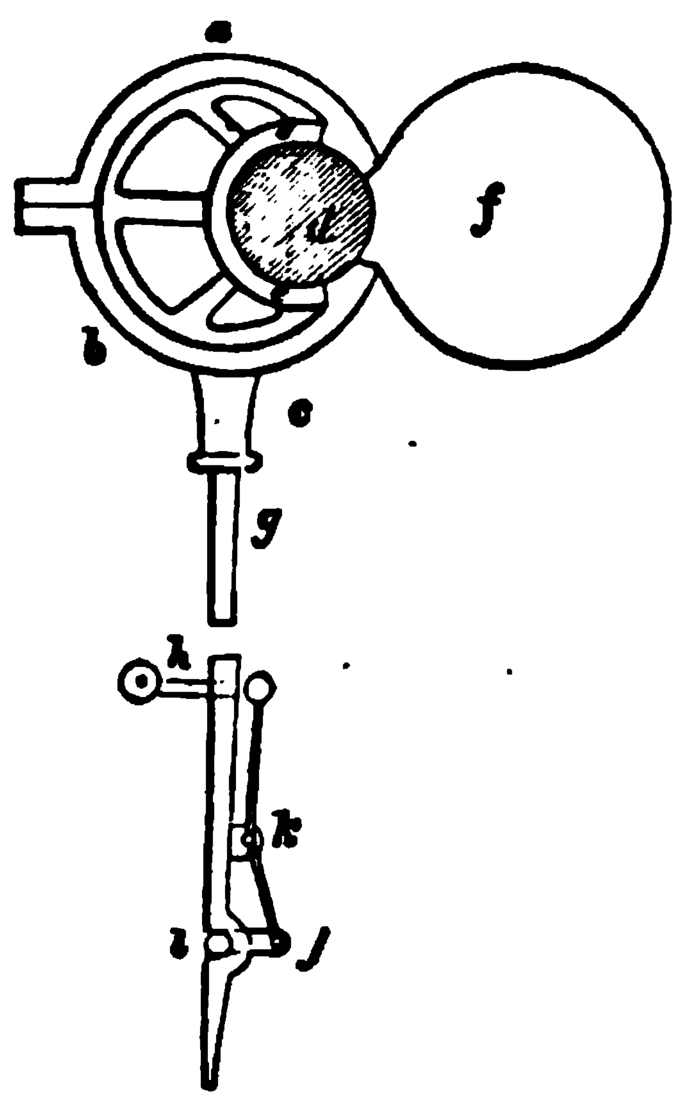
As it is necessary that a certain advance be given to the eccentric over the crank, in order to insure the direction of the engine's motion, some peculiar arrangement must be provided in those engines which occasionally require to be reversed.

There are two forms of reversing-gear in common use: one generally employed for paddle-wheel engines, and the other for screw-propeller and locomotive engines. The former, however, shall be first described.

Fig. 84 represents the ordinary single eccentric reversing ar-

rangement. In this case the eccentric is not keyed on to the shaft, but so arranged that the latter is capable of revolving free within it. *a b c* is the eccentric, which, in order to prevent its falling to the bottom of the stroke by its own weight, is counterbalanced by the weight *f*, so that the eccentric may remain in any position

Fig. 84.

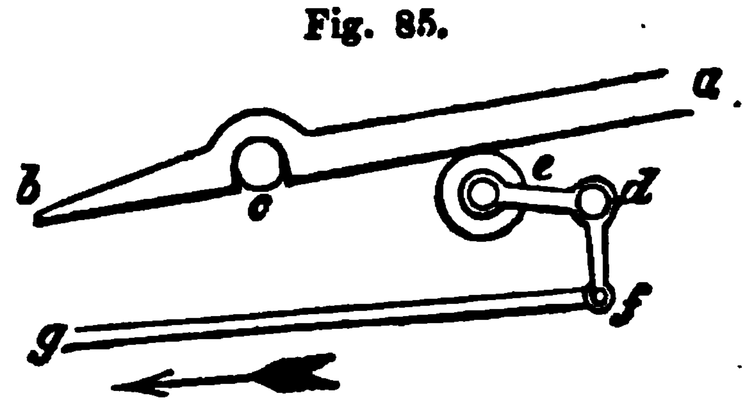



while the shaft revolves. Upon the shaft is bolted a segmental collar, *e e*, either extremity of which coming in contact with the inner part of the balance weight *f*, which is bolted to the eccentric, will propel the latter. If we suppose the engine to be stopped, and the slides moved by hand to such a position as will cause the engine to start in a direction contrary to that in which it was running, the segment at collar *e* will retire from the balance weight on one side, and having performed a portion of a revolution, will come in contact with it on the other side, and cause the eccentric to revolve with the shaft; after which the motion of the engine will continue uniform until some further adjustment is made.

It is however necessary to provide some means whereby the eccentric rod may be temporarily disconnected from the slide-valve gear, in order that the latter may be moved by hand to the position necessary to reverse the motion of the engine. The lower part of the eccentric rod arranged for this purpose is shown at *h i*. At *i*

is a pin attached to a lever acting on a way shaft to which the limbs by which the slide is moved are attached. This pin gears in a notch or gab in the extremity of the eccentric rod, which is called the gab lever. Behind this pin the gab lever is perforated and a strip of metal inserted as shown at *l*. Now it is evident that if this strip of metal be forced forward, it will fill up the notch, forcing the pin out of it, thereby disengaging the valves: nor will the pin be able to re-enter the notch until the strip of metal is withdrawn. All that is now required is the means of acting this strip of metal, and such means are furnished by the lever shown. It is fixed on a fulcrum at *k*; the lower extremity is attached to the strip of metal, and the upper one to a handle *h*, which passes through the gab lever. It is evident that by pushing the handle towards the gab lever the engines are thrown out of gear; whereas by pulling the handle from the gab lever, the engines are allowed to fall into gear. Some means must of course be provided to retain the handle *h* in position, but these are obvious. It is evident that the sliding piece may be made in one with the lever, instead of being jointed to it as we have described. In some cases the stop is dispensed with, and the gab lever is raised when necessary by means which may be rendered more clear by Fig. 85. *a b* is the

Fig. 85.




gab lever, *c* the pin communicating with the slide-valves, *d* is a short shaft on which is an arm, *d e*, carrying at the extremity *e* a pulley close under the gab lever. To the short shaft is also attached an arm, *d f*, having a link, part of which is shown at *f*, attached to it. Now it is evident that by moving the link *g f* in the direction indicated by the arrow, the gab lever will be raised clear of the pin *c*. The other class of reversing gear now requires attention. The arrangement already described is evidently inappropriate to locomotive and other high-speed engines, as it would rapidly be destroyed by the vibratory action, even if it were pos-

sible to work with it. Hence, in engines of this class we find that two eccentrics have generally been used, one for the forward motion and one for the backward motion, either of the eccentrics being capable of being put into gear with the valves. In the first instance the extremities of the eccentric rods were furnished with forks, which, by an ingenious but complicated arrangement, were worked to gear with the slide in such a manner that when one fork was in gear the other was out, so that either eccentric could be brought into action, according to circumstances. This arrangement has however been long since superseded by that beautiful contrivance known as the link motion, which will now be described with the assistance of Fig. 86.

Let *a* be the forward eccentric, that is to say, the eccentric which is set to give the engine a forward motion, and let *b* be the backward eccentric. The lower extremities of the eccentric rod are attached to a link, *c d*, within which is a block connected with a slide

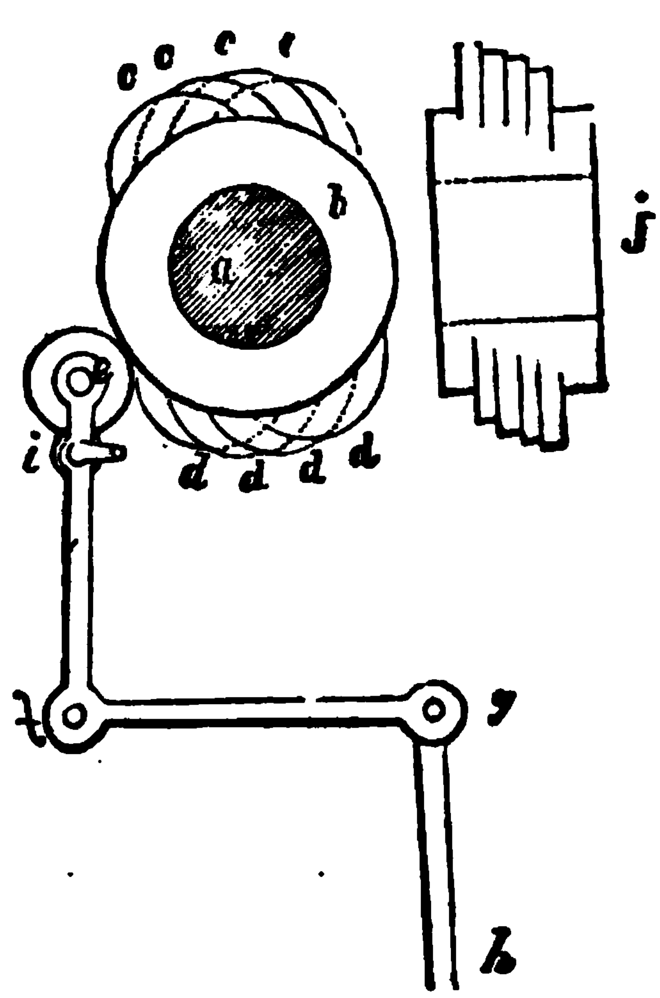
Fig. 86.

rod, *e*. To the back of the link is attached an eye, *f*, from which a link proceeds to the end, *d*, of an arm, carried by a short shaft, *g*, which shaft has also an arm, *g h*; and to the extremity, *h*, is attached a link as shown. Now, it is evident that by moving this link in the direction of the arrow, the link *c d* will be raised, and sliding over the block attached to the slide rod the latter will be brought under the control of the eccentric *b*. By a reverse method it will be brought under the action of the eccentric *a*. It is not necessary that the block should be quite at the end of the link,

but it may be at some intermediate point, and by adjusting this position the quantity of steam admitted to the cylinder is also adjusted.

In some cases the link *c d* is suspended from a fixed point, and a connecting rod is then jointed to the slide rod, and the extremity of this connecting rod is attached to a movable link, *d f*. This arrangement, known as the link motion, is in the locomotive engine worked by a hand-lever, but in screw engines it is very commonly regulated by a hand-wheel. Having disposed of the eccentric whereby the slide-valve is worked, a description of the means of working the expansion-valve is necessary. This is effected by means of cams, of which the arrangement is shown Fig. 87. *a* is the main shaft, *b* the boss upon which various cambers are placed side by side, in positions corresponding to the points at which it may be required to cut off the steam; *e* is a roller which rests against any one of the cams, as may be required;

Fig. 87.




it is carried at the extremity of an arm attached to a short shaft, *f*. The roller will, twice during every revolution, that is, once in every stroke of the engine, be forced back by the cam, whereby the link *g h* will be raised, and the expansion-valve shut. The roller is moved horizontally to bring it under the action of any cam by means of a screw worked by a handle eye, which screw

carries a fork or guide, embracing the pulley *e*. Of course the pulley must only be shifted when resting on the plain part of the boss *b*. Another view of the expansion cam arrangement, showing the edges of the cambers, is seen at *j*.

With regard to the construction of eccentrics and cams, it only remains to be observed that the moving parts must be very accurately fitted to each other by the usual means, and the other parts, with the exception of the sides of the eccentrics, be brought up to bright surfaces by turning, planing, and filing. With regard to the construction of the fly-wheel there is but little to be said. It is usually of cast-iron, in one or more pieces, according to circumstances. It is bored out accurately, and firmly keyed on to the crank shaft, and if very heavy it should have bearings to the shaft on each side. We have known cases in which the fly-wheel was retained in position by a screw running through the boss of the wheel into the shaft; but this is a clumsy arrangement, and may give rise to much difficulty if it is required at any time to remove the fly-wheel from the shaft.

It is very advantageous in many cases to make the wheel with a cast-iron boss or rim, and with wrought-iron arms, which may readily be done by imbedding bars of wrought-iron in the mould previous to casting the metal, which will then envelope the extremities of the arms, and in cooling it will firmly grip them, and the hold may be increased by notching the extremities of the arms previous to placing them in the mould.

Those elements called governors, next require attention; and of these a very great variety have been produced. They may, however, be arranged under two heads, viz., those which have for their principle the equilibrium of the force generated by the velocity of the engine with some external force, and those which regulate the admission of steam in proportion to the resistance which the engine has to overcome. In the first class we have the conical pendulum or common two-ball governor, in which the centrifugal force is balanced by the attraction of gravitation; we have also in this class other varieties, some with two and some with four balls, in which the centrifugal force is resisted by the elasticity of a helical spring; and among these Silver's four-ball marine-engine governor stands forth pre-eminently for practical utility.

Plate XII. represents a number of governors to which our attention has been lately directed especially in order to determine the relative values, or rather the relative delicacies of various kinds. Fig. 1 represents the commonest form of governor, which consists of two balls, so arranged that at a given velocity the amount of steam admitted to the engine is, upon certain data, sufficient for the work it has to perform. It is however no difficult matter to show that this arrangement, in common with others of the first class, gives results far from accurate. For instance, let us suppose that an engine is supplied with steam of uniform pressure, and that it is working at a certain given velocity, which velocity it is required to maintain, with very slight variations. Let us suppose that the engines to which we refer are employed to drive the machinery in the works of a mechanical engineer; then they will be subject to constant variation of work to be done, and if it is imagined that some extra machine, say a circular saw, is thrown into gear with the engine, more power will be required to do the work of the establishment; hence the steam-pipe must afford a wider passage to the steam, which of course cannot be done but by opening wider the valve which is controlled by the governor. Thus, for instance, to take an example, if we require one-tenth more power, we must absorb an equal additional quantity of steam, or the valve must be opened so as to give so much more area of steam-passage, the amount of friction on the sides of the steam-passage being, on this occasion, omitted. It is unnecessary to encumber our space with the exact calculation of this matter, but it is very simple, requiring only the most elementary principles of plane trigonometry for its solution; hence we feel justified in omitting it. We may however observe, that the width at any point of real steam-passage will vary very nearly as the verse sine of the angle described by the valve from the position at which the steam is shut off, and this verse sine will vary but slightly for considerable angular variation, until the angle described amounts to about 45°; hence, when the throttle-valve is but slightly open, and any considerable amount of extra work is thrown upon the engine, a very considerable angular deviation of the throttle-valve will be requisite in order to afford sufficient area of steam-way, and to obtain such deviation the governors must of necessity collapse to a notable extent, and remain in such position, for the

maintenance of which a reduced velocity of the engine is indispensable.

Fig. 2 represents a form of governor in which the elastic resistance of a spring is employed in the place of gravity; hence this apparatus may be used in positions deviating from the vertical, or in other words, the plane of revolution of the balls need not necessarily be horizontal, which position is the only one in which the common governor is efficient.

Similar in action to the last described governor is Silver's marine governor, but the disturbing effects produced by variation of position, are still further obviated by the employment of four balls instead of two.

Figs. 3 and 4 are illustrative of governors, in which the centrifugal force is, as in the last case, opposed by the elasticity of the spring, but these forms have been illustrated for the purpose of comparing them with each other; for although at the first glance it may appear very different, yet they are but modifications of one form, being identical in principle. In Fig. 3 we have the balls attached to the ends of bent levers, *a a*, to the other extremities of which are jointed links, *a b*, attached to a sliding collar, *b b*, which is in connection with a spiral spring placed around the main spindle of the governor; *c c* are the fulcra of the bent levers. Now, it is evident that we may alter the angle *a c a* without destroying the principle of the apparatus. Let us suppose that the two arms of the bent lever are made parallel and of equal length, then we arrive at the form shown Fig. 4, which also presents many points of similarity with the form shown at Fig. 2, and it remains for us to determine which is the more delicate, that is to say, in which governor the greatest effect upon the valve will be produced by a given degree of variation of velocity.

In order to satisfy ourselves on this point, it is not necessary to have recourse to intricate methods of analysis, for it is a matter of observation that in Fig. 3 the balls must become horizontal before they can cease to have further effect upon the spring; or in other words, so long as the centrifugal governor can be used, the desired effect will be produced by this form; whereas in the form shown in Fig. 4, as soon as the arms of the governor have risen to an angle of about 40 degrees to the horizon further action becomes impossible, as the links *a b* will then permit of no further separa-

tion of the balls; and the delicacy of this apparatus in every position is equally inferior to that of the arrangement illustrated in Fig. 3.

The foregoing examples of the first class of governors illustrate the principles of a great variety, but it would be useless to attempt to give any complete account of all the various forms which have been brought forward; we may, however, observe, that in some instances the resistance which is afforded by gravity or helical springs, in the cases described above, is supplied by the resistance of the atmosphere to revolving vanes, or by the resistance of a fluid to vanes, or to a screw revolving in it.

Figs. 5 and 6 are illustrative of a governor of the second class, Fig. 5 being a plan of the arrangement, and Fig. 6 a side elevation of a portion of the same. This contrivance adjusts the quantity of steam admitted to the engine to the power to be exerted; its arrangements and action are as follows. In the illustrations, *a* represents a bevel wheel, to which the power of the prime mover is, in the first instance, transmitted; *c* is another bevel wheel attached to the shaft, from which the power is transmitted to the machinery to be driven, a third bevel wheel, *b*, serving to connect the two former ones, *a* and *c*. The wheel *b* runs loose upon the turned extremity of a lever, *b e*, which has its fulcrum at *d* in a line with the axis of the main and working shafts, so that the wheel *b* may revolve about the centre *d*, without being thrown out of gear with *a* and *c*. To the extremity *e* of the lever *b e*, is attached a rod, carrying at its lower extremity a piston fitted to work air-tight in a cylinder, *f*; the upper part of this cylinder is closed, containing condensed air. Let us now suppose that the wheel *a* is caused to revolve in the direction indicated by the arrow, then it is evident that if the resistance offered to the revolution of the wheel *c*, be greater than that offered to the revolution of the wheel *b* about the centre *d*, then will the latter take place, the wheel *b* descending; but in so doing it will necessarily raise the extremity *e* of the lever *e b*, and with it the piston in the cylinder *f*, by which the air above the piston will be still further compressed, so that a continually increasing resistance will be offered to the descent of the wheel *b*, and at length the point will be arrived at where its position with regard to the centre *d* remains unaltered, the motion imparted to it by the wheel *a* being transmitted to that at *c* on the working

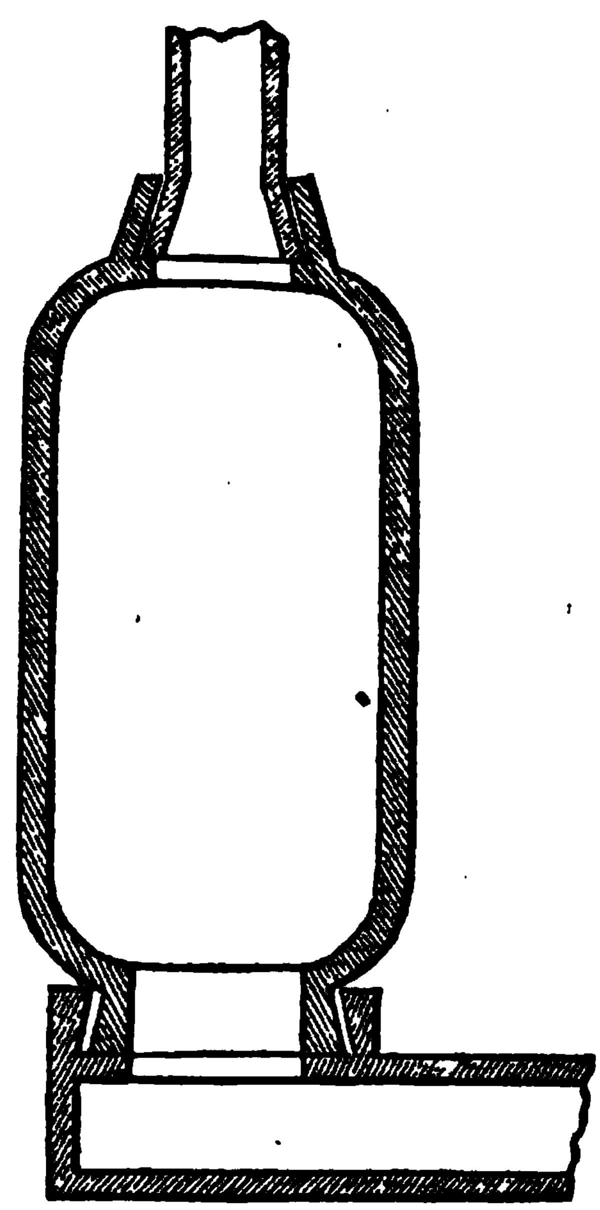
shaft, and the elevation or depression of the wheel *b* will thus be in proportion to the resistance offered by the machinery to be driven. The lever *e b* is so connected with the throttle valve of the engine, that the greater the elevation of the piston in the cylinder *f*, the greater will be the quantity of steam admitted to the working cylinder of one engine, and *vice versa;* hence, the greater the resistance to be overcome, the greater will be the quantity of steam admitted to the engine, so that the velocity may remain uniform. The compressed air in the upper part of the cylinder *f*, may of course be replaced, if deemed desirable, by a spring. If when the engine is running, an extra load be thrown upon the working shaft, the wheel *b* descends until the resistance offered to its descent is again equivalent to the work to be done, and in so doing the throttle-valve is opened to a greater extent than before; but if, on the contrary, a portion of the work be thrown off, the pressure of the air in the cylinder *f* presses down the piston, and raises the wheel *b* until the opposing forces are again in equilibrio, the throttle-valve being thereby partially closed. It is of course necessary in the first instance to adjust the opening of the valve for some given position of the governor, and this is done by means of a right and left-handed nut, which governs the length of one of the links connecting the governor and the throttle-valve. No special remarks are requisite as to the construction of governors, beyond the observation that the parts must be very accurately fitted together by means of the processes already set forth.

Let us now proceed to the description of the vessels employed for condensation of the steam after it has done its work in the cylinder of the condensing engine. These condensers are of two classes; first those in which the steam is condensed by water, and secondly those in which it is condensed by contact with cold metallic surfaces, these latter constituting what are termed surface condensers.

The apparatus used for effecting the condensation of the exhaust steam by the first method is usually exceedingly simple, consisting of a cylindrical vessel; or if this form be not convenient, any other may be adopted according to the requirements of the engine to which it is intended to attach the condenser, within which vessel is placed a perforated jet rose or tube connected with the exterior of the condenser by means of a pipe passing through the

side of the same, and furnished with a cock to afford a means of regulating the admission of water to the condenser. The action of this arrangement is as follows. Before starting the engine, a tank, in which the condenser is fixed, is filled with cold water, and subsequently kept full; steam is then admitted to the condenser to expel the air which formerly filled it, which it does either through a conical valve placed at the top of the condenser, called a snifting valve, or otherwise through a valve at the foot leading to the air-pump. As soon as all the air is displaced, the cock attached to the pipe which terminates within the condenser is opened, and water flows into the condensing vessel, where it comes in contact with the steam within the same, and reduces it at once to a liquid condition, leaving a vacuum approaching more or less nearly to an absolute vacuum, according to the management of the apparatus. Fig. 88 represents a vertical section of one form of condenser. It

Fig. 88.



is a species of swelled pipe; the upper and lower extremities or necks are bored out so as to be of greater diameter at their inner than at their outer ends. Into these necks are inserted the extremities of pipes of corresponding form, as shown, the surrounding

interstices being filled up to make good the joints. The upper pipe brings the exhaust steam from the cylinder, and the lower one communicates with the air pump.

Another form of condenser consists of a cast-iron cylinder fitted with a cover, and having the passage which serves to communicate with the air-pump cast on it. The condensers used in marine engines are not usually immersed in water, on account of the confined space in which they are employed.

Condensers of the second class are far more intricate and varied in their forms than are those which we have just described, the object in using these being to recover pure and unmixed the water resulting from the steam which has passed through the engine, which is very desirable when clean water cannot be obtained, or when the water contains much mineral matter, such as is the case with sea-water. Attempts have been made from a very early period down to the present time to produce a surface condenser which should be efficient, the first consisting of two thin cylinders of large diameter, placed concentrically one within the other, water being allowed to circulate around the outer tube and within the inner one, the steam to be condensed being introduced into the annular space bounded by the peripheries of the two concentric cylinders. This contrivance was, however, found in practice to be unequal to the duties required of it; it was consequently abandoned, and condensers of the first class were for a time exclusively employed. Subsequently a form of surface condenser was introduced, which has proved more successful. It consisted of a number of tubes of small diameter, around which water was permitted to flow, and into these tubes the exhaust steam was passed and there condensed, and from the condenser the water thus formed may be pumped directly back to the boiler. This apparatus is that invented by Samuel Hall. Since the production of this form of surface condenser, a great variety have been introduced to public notice, and it has also been attempted, in some instances with success, to use air as the cooling medium in the place of water, in order that the principles of condensation might be applied where sufficient water for the ordinary condensing apparatus could not be obtained. Craddock's condenser, intended for use with either air or water, consists of a number of small tubes attached at the top and bottom to vessels which serve to afford com-

munication amongst all tubes. This condenser, being caused to revolve rapidly in air or water, is found tolerably efficient, as with the former medium a vacuum equal to nine pounds pressure per square inch may readily be obtained. Surface condensers, to be used with air, have also been formed of thin plates fixed parallel to each other, between which is passed the steam to be condensed. When air condensers are attached to locomotive carriages they may be fixed, as the velocity of the carriage itself is sufficient to cause the required circulation of the air. With regard to the construction of the various forms of condensers, it is only necessary here to observe that those of the first class merely require to be turned, planed, or faced at the joints, and those of the second class are somewhat similar in their construction to multitubular boilers. An account will be hereafter given.

The next element to which our attention is directed is the air-pump, by means of which the condensed steam, the water used for condensing it, and the air which is always contained in the latter, is withdrawn from the condenser, together with any portion of steam which may escape condensation, so that the vacuum produced previous to starting the engine may remain unimpaired while it continues in action.

The air-pump consists of a cylinder accurately bored, within which the piston moves air-tight. There is a valve at the foot of the air-pump, opening in a such a manner as to allow of the passage from the condenser to the air-pump of such matters as are to be withdrawn from the former; whilst another valve at the top of the pump allows of the exit and prevents the return of the same from and to the pump. The water, &c., below the piston is allowed to pass through it by means of valves opening upwards, the action of the apparatus being as under. As the piston, or bucket as it is called, of the air-pump rises, the water, air, and vapor in the lower part of the condenser pass through the bottom valve into the lower part of the air-pump · on the descent of the air-pump bucket, the water, &c., beneath it, forces the valves formed in it open, and passes through to the upper side, and when the bucket again ascends, the water upon it is raised and forced through the upper valve into the hot well. This constitutes what is termed a single-acting air-pump. When the pumps are made double-acting the bucket is replaced by a solid piston, and two sets of valves are

employed, so that when the piston ascends, it draws in water below, and forces other water out above, and on its descent it draws above and forces below, so that the pump works during both the up and down-stroke; whereas, in the former case the pump is only effective during the up-stroke. The material of which the cylinder of the air-pump is formed is frequently cast-iron, but it should be lined with brass or Muntz metal; and this is especially necessary when sea water or foul water of any description is used; the same material should also be applied for air-pump rods. Iron rods, covered with brass, are very frequently used, but they are found to waste away where they are joined to the bucket. The method of constructing air-pumps is as follows: The cylinder, if of solid brass, is simply bored out in precisely the same way as a steam cylinder; but when it is lined it is first bored out, and the lining then bent, introduced into it, and made to fit firmly by hammering it on the inside, whereby the lining is expanded, so that the casing takes a firm grip; the lining is then bored out to the required size. The piston or bucket is accurately turned to fit the cylinder of the pump, and packed generally with hemp, which is tightened up by means of a junk-ring. Metallic packing has occasionally been used, but the vacuum obtained is not nearly so good, and, on the whole, it is inferior to hemp. The valves, if of metal, are accurately planed or turned, and then faced up or ground; various descriptions are used, but we shall not pause here to describe them, as a complete account will be given in a subsequent chapter.

With regard to the feed-pump, it is only necessary here to observe that what are called plunger-pumps are most generally employed; for a description of which the reader is referred to the chapter on pumps.

In concluding the present chapter, we may observe that it is the practice of some manufacturers to grind the steam-cylinders and the piston rods and similar parts; it is advisable to draw-file throughout their length, and polish.

In this chapter we have endeavored to explain the form and mode of manufacture of the principal elements of the various kinds of steam-engines, omitting, however, various minor arrangements which require no special comment, and the action of which will be illustrated by examples.

## CHAPTER XIV.

### ON PUMPS AND VALVES.

It is proposed in the present chapter to give a general account of those pumps which are most commonly employed in practice to raise water, avoiding any thing further than a mere reference to such forms as are of doubtful efficiency. The first class which we shall consider is that which includes bucket or piston pumps, which are those most commonly used for the ordinary purposes of life; the principle of their action is as follows.

Let us suppose that we have a cylinder fitted with a piston, in which there is a valve capable of opening upwards, so as to allow of the ascent of a fluid through the piston, but effectually preventing its return. Let the bottom of the cylinder be closed, and also furnished with a valve opening upwards, at the termination of a short pipe, of which the lower extremity is immersed in water; let the piston fit the cylinder water-tight, and let it be at the bottom of its stroke. If the piston be now raised, there will evidently be a vacuum beneath it, into which the water will be forced up the short pipe, by reason of the external pressure of the atmosphere. The piston having arrived at the top of its stroke, is stopped, when the valve at the bottom of the cylinder will close by reason of its own weight; and if the piston be now caused to descend, the water beneath it will raise the valve in the same, and pass through to the upper side, and when another up-stroke is made, this valve having closed, the water above the piston will be raised, and will flow over the top of the cylinder, the lower part of which will again be filled. The upper end of the cylinder or pump-barrel may be closed, and supplied with a valve to allow of the exit of the water raised, and to prevent its return upon the piston.

There is, of course, a limit to the height of the pipe which effects the communication between the bottom of the pump-barrel

and the water to be raised, as it is evident that the pressure of the column of water under the pump-barrel cannot exceed that of the atmosphere. The height of a column of water which balances the atmospheric pressure is nearly 34 feet, hence the suction pipe of an ordinary pump should not, in vertical height, exceed 30 feet. This form of pump, when fitted with an exit valve at the top, is sometimes called a lifting pump.

Piston pumps are also made with solid pistons, that is to say, having pistons solid throughout, not furnished with a valve. The water, in this case, is drawn into the lower part of the pump barrel, through a valve opening inwards, and expelled through another valve opening outwards; this apparatus is called a forcing pump. The upper extremity of the cylinder may also be furnished with inlet and outlet valves, that water may be drawn and forced above as well as below the piston, in which case the pump rod through which motion is imparted to the same, passes through a stuffing-box in the pump cover; during the up-stroke, this pump is drawing beneath and forcing above the piston, and during the down-stroke, the contrary takes place; this is called a double-acting force-pump. The packings of these pumps are usually cupped leathers, or leather collars, which may be easily made by pressing the leather into form under the influence of moisture and heat, after which they may be turned by means of suitable tools.

Piston pumps are sometimes furnished with a trunk, being then called trunk pumps. The trunk is, in fact, a hollow piston rod, of cylindrical or oval section, the object of which is to admit of the use of a long connecting rod which passes down the trunk, being jointed to the piston at the bottom of the same. The various forms of valves used for the buckets, and to regulate the entrance and the exit of the water, will be subsequently considered.

We will next turn our attention to the form and principle of action of that class of apparatus which comprises the various descriptions of plunger pumps. A plunger pump consists of a barrel or cylinder, slightly contracted at its upper extremity, and entirely closed at its lower end; within this cylinder another solid cylinder or plunger works; its diameter being a little less than that of the pump-barrel, so that it may not come in contact with the sides of the latter. The plunger thus formed works water-tight through a stuffing-box packed with leather or hemp, and

placed at the upper or contracted extremity of the pump-barrel, which is itself furnished with two valves, one of which opens inwards, the other opening outwards. The action of this apparatus is as follows. When the plunger makes an up-stroke, it tends to leave a vacuum equal to its own bulk in the pump-barrel; this space is, however, immediately filled by water entering through the inlet valve; on the descent of the plunger the same quantity of water is expelled through the outlet valve; this pump also acting as a forcing pump, and is used generally for feeding steam-boilers and for working hydraulic presses, and is very frequently applied to large pumping engines. When the plungers are of very great size, they are frequently made hollow, in order to save weight; but it sometimes occurs that it is necessary for them to be heavy, as in the pumps of the Cornish engines, where the plunger is raised by steam-power and descends by the gravity of its own weight alone, or aided by extra weights placed upon the plunger pole. Plunger pumps are also sometimes made as trunk pumps, in which case the plungers themselves, being hollow, constitute trunks.

The plungers of these pumps having been accurately turned, should be draw-filed through their whole length, the packings, if of leather, being lubricated with water, and if of hemp, with oil. The efficiency of pumps of the two classes described above, depends principally upon the valves, and if these can be made perfect in their action, then will a barrelfull of water be raised at each stroke of the pump. The effective work done by the pump is found from the expression

$$w = 10 \times q \times h$$

in which $w$ represents the work done during one stroke, expressed in foot pounds; $q$ the quantity of water raised during one stroke, expressed in gallons; and $h$ the height in feet from the level of the water in the well to the point of discharge, that is to say, the height to which the water is raised.

Centrifugal pumps are now occasionally used for raising water when the lift is not very great; they act by imparting centrifugal force to a mass of water in a cylindrical box or casing. The moving part of the pump consists usually of a shaft, upon which are placed arms carrying vanes, the whole forming a species of fan. When this is caused to revolve rapidly, rotatory motion is

imparted to the water in a casing which surrounds it, which causes the latter to press against the periphery of the casing, and to pass out at an aperture in the same, whereby a partial vacuum occurs about the axis of the fan, into which water flows through a suction-pipe. The advantage of this pump is, that it is capable of passing impediments which would choke the valves of an ordinary pump, but its efficiency is less.

Many years since, an apparatus called a spray-pump was proposed, constructed on principles derived from the following considerations. It was found that if water be allowed to fall freely through air in a fine shower, the velocity with which the drops fall does not exceed about twelve feet per second; hence it was concluded that an upward current of air, moving with a velocity of, say twenty feet per second, passed through a stratum of water, will carry with it an upward shower to any required height. This apparatus was, however, found to be practically far from economical, which may be attributable, in a great measure, partly to the fact that a high-pressure engine was used to propel the fan which created the current of air, and partly to the inefficiency of the fan itself.

We have mentioned this last contrivance on account of the ingenuity of the principle on which it is based; but it is quite unnecessary to give any account of the designs innumerable which have been brought forward for raising water, and which have never been carried successfully into practice.

It now remains to describe the various forms of valves most commonly used for pumps. The clack-valve is probably the oldest, and is very simple. It consists of a flap of leather, or other suitable material, covering an orifice and fixed down at one edge, so as to open, as it were, on a hinge; the leather flap requires to be covered top and bottom on the central part with plates of metal, in order to add to its weight, so that it may close rapidly and impart to it sufficient rigidity. These valves are frequently made of india-rubber closing upon a grating, instead of over one large opening, and a method has recently been brought forward, whereby that part of the valve which is bolted down to form a hinge is made of hard india-rubber, thereby obviating the necessity of using strips of iron to form a hold for the bolts which formerly existed. Guards are fixed over the valves to prevent

them from rising too high. When one piece of leather or other substance used for the valve is fastened down in the centre, so as to form two clacks, the arrangement is termed the butterfly clack. The principal disadvantages attendant upon the adoption of this form of valve in large pumps, are, firstly, the loss of water caused by the slowness with which the valve closes, the column of water above it beginning to return before the valve reaches its seat; and secondly, the great concussions produced by the fall of the valve with the column of water upon it, the loss of water during the closing of the valve sometimes amounting to one-eighth of the whole quantity raised.

The next form of valve to which we shall refer is the conical valve, which consists of a flat or slightly-curved plate of metal, of which the periphery is in the form of a frustrum of a cone, fitting into a seat of corresponding form. In order that this valve may rise vertically, it is sometimes furnished with a spindle, moving in guides, and sometimes furnished with a tail or stalk in the form of a triple feather, proceeding from its lower surface, and fitting the pipe beneath the valve. Stops are placed above the valves to limit their rise.

Another form of valve consists of a short india-rubber tube, flattened at the extremity. When water is forced into the open end of such tube, it passes through, forcing open the flattened extremity; but in the contrary direction, pressure closes the tube more effectnally.

It is a great desideratum to obtain a valve which shall close rapidly, so that it may reach its seat before the column of water above it begins to return, whereby loss of water is obviated and concussions avoided. In order to obtain effects so desirable, various forms have been produced, of which the best is the double-beat valve of Messrs. Harvey and West, of which a vertical section is shown, Fig. 89. This valve has two seatings, *b b* and *c c*, and when the valve is raised by the pressure of the water beneath it, the latter flows out in the directions indicated by the arrows. *a a* Is a collar which prevents the valve from rising too high; washers of leather are placed beneath this collar to obviate the blow of the valve in rising,

Another form of valve, by Jenkyns, consists of a disc-valve, itself perforated, so as to form the seat for another disc-valve; the

number thus superposed depending upon the diameter of the orifice which the valve is designed to close. Another description

Fig. 89.

of valve which has been proposed, consists of numerous concentric annular orifices closed by rings, and this has recently been improved upon by making the rings of india-rubber, as done in Mr. Hosking's valve.

A valve commonly used for locomotive feed pumps, consists of an accurately-formed sphere of metal, falling into a spherical seat, its rise being regulated by guards.

The surfaces of contact between valves and their seats must be got up by scraping or grinding, so as to exhibit the highest degree of accuracy attainable. And when of metal, they should both of them be of the same metal, as otherwise galvanic action is produced, causing the corrosion of that surface which is formed of the most electrically-positive metal. Seatings formed of hard wood, placed with the grain endways, and kept constantly wet, are found satisfactory in practice.

Before concluding our observations upon valves, a few remarks on the height of rise which should be allowed, and upon the power required to work them, may not be inappropriate.

It is evident, that for the whole effect of a valve to be obtained, its rise should be such that the waterway between the seating and the edge of the valve be not less than the area of the valve. For a semicircular clack-valve the extreme rise is found as follows

Let $r$ = radius of valve, $h$ = height of rise, the area of the valve will evidently be

$$=\frac{3 \cdot 1416\, r^2}{2}$$

and the waterway between the seating of the valve and the edge of the same will be

$$=\frac{3 \cdot 1416\, r\, h}{2}$$

hence the whole area could only be utilized when the valve opens to a vertical position, which is of course inadmissible; hence valves of large radius must be employed.

For disc-valves, we have, for the area of the valve,

$$3.1416 r^2$$

and for the waterway between the valve and its seating

$$6 \cdot 2832\, r\, h$$

hence, the proper rise is found from the expression

$$h = \frac{r}{2}$$

This also applies to the ball-clack.

In the double-beat valve, let $r$ = the lesser, and $r'$ the greater diameter, for the seatings; then the effective area of the valve is

$$= 3 \cdot 1416\, r'^2$$

and the area of waterway given by the rise of the valve is

$$= 6 \cdot 2832\, h\, (r + r')$$

hence

$$h = \frac{r'^2}{2\,(r + r')}$$

It may be observed that if

$$r = r'$$

the valve is not affected by any difference of pressure above and below it; it is then called an equilibrium-valve, which is much used in Cornish pumping engines, and the nearer the value of $r$ approaches to $r'$, the greater will be the pressure required per square inch to open the valve.

# CHAPTER XV.

## ON BOILERS.

In a previous chapter we have set forth the principles upon which steam-boilers generally are constructed, and in the present we propose to render an account of those generally used; for which purpose we have carefully selected such examples as appeared best suited to give a general idea of the objects aimed at in the construction of steam-boilers and of the means employed to attain such objects.

Perhaps the simplest form of boiler now largely employed to generate the steam requisite to actuate steam-engines, is that known as the Cornish boiler. It consists of an external cylindrical shell, through which passes a tube which serves to carry the flame and heated air from the furnace. The extremities of the boiler being closed by flat plates, the water is contained in the space included between the inner and outer cylinders.

The thickness requisite to each part of the boiler may be determined from the following formulæ with quite sufficient accuracy for all practical purposes, the boiler being made of wrought-iron.

Let $r$ = radius of outer shell, $r'$ = radius of inner shell or flue, $t$ $t'$ thickness of outer and inner shells, $t''$ thickness of end plates, all in inches, $l$ = length of flue in feet, $p$ = greatest pressure in lbs. per square inch to which the boiler will be subjected.

Then

$$t = \frac{p.\,r.}{7500}$$

$$t' = \sqrt{\frac{p.\,l.\,r'}{60{,}000}}$$

and

$$t'' = 0{\cdot}0085 \left\{ r - r' \right\} \sqrt{p}$$

Formulæ for determining the evaporative values of boilers have been given already in Chapter X.

In order to exemplify the above-mentioned form of steam-boiler we have shown a longitudinal section of such an one on Plate XIII. The boiler there represented has been erected by Mr. Wicksteed to supply the new pumping engine at the Scarborough Waterworks, at Cayton Bay. The boiler consists of an external shell and an internal flue, and is furnished with the usual appendages, safety valves, pressure guages, &c. It has been the custom to attach to such boilers a pipe to carry off the steam escaping from the safety valve, but it is evident that under proper management no such escape should occur; hence that detail is not added to the boiler illustrated.

These boilers are manufactured by riveting together a sufficient number of wrought-iron plates of suitable size, and the work should be so arranged as to break joint; that is to say, the longitudinal joint in one pair of plates should occur in a line with the centre of a plate in the next ring of plates, so that a horizontal section through the shell of the boiler at this place may exhibit half joint and half solid plate, and it is upon this supposition that the above formula for the outer shell has been calculated; for if the joint runs longitudinally from end to end of the boiler it will become

$$t = \frac{p. r.}{5000}$$

and if the metal were solid throughout

$$t = \frac{p. r.}{10,000}$$

From this formula it is evident that the thickness of a vessel subject to internal pressure, of circular section and with thin sides, should vary directly as the radius and as the pressure; hence if radius and pressure both increase, the corresponding thickness will increase very rapidly; hence it becomes desirable that when very high pressures are requisite the radius should be as small as possible, to avoid the use of metal of thickness greater than is absolutely necessary to satisfy the conditions of safety.

In accordance with these views, various designs have been originated in order to obtain boilers which should possess at once

the qualifications of strength and lightness, and one of the best adapted to these requirements is illustrated in vertical horizontal section at Plate XIV., having been invented and patented by Mr. Craddock, and capable of working safely under a pressure of from two to three hundred pounds per square inch.

This boiler will be observed to consist of numerous water tubes placed side by side in close contact around a fire, and forming as it were the sides of the furnace, and, by the form thus produced, offering a very large surface to the action of the flame in comparison to the contents of the tubes, and the smaller the tubes become the greater is this effect. The area exposed to the action of the heat is found from the following formula:

Let $d =$ diameter of furnace in feet, $h =$ total height of tubes above fire-grate in feet, $a =$ absorbing surface in square feet,

$$a = 5\ dh. \text{ nearly.}$$

Taken vertical surface as equal to half the horizontal surface, the nominal horse-power becomes

$$= \frac{2{\cdot}5\ d\,h}{8{\cdot}1}$$

$$= 0{\cdot}308.\ d.\ h. \text{ nearly.}$$

These water tubes terminate top and bottom in stout wrought-iron vessels called hearts, and the upper heart is surmounted by a steam-dome, placed in the uptake of the chimney, whereby the steam is partly dried; to this dome the gauges, valves, &c., are attached. The water tubes are deviated from their vertical positions at top and bottom to allow the entrance of air to effect combustion and the exit of flame and heated gases; and they are also deviated in front of the grate to admit of the insertion of a fire door. The course of the current of air and gases is as follows. The atmospheric air required to effect the combustion of the coal enters under the grate through an orifice left beneath the furnace door, whence it passes through the incandescent fuel and upwards to the bottom of the upper heart, whence it escapes through the openings between the upper extremity of the tubes; thence it passes down between the outside of the tubes and the masonry, and finally escapes into the uptake. The horse-power equivalent to the inner absorbing surface has been given above, and a similar formula will give that which is due to the external absorbing

surface. This boiler was found to work very economically, but by reason of the small quantity of water which it contains requires some rather delicate contrivance to regulate the draft, which is supplied by a self-acting damper opened by an air spring, which consists of a quantity of air imprisoned in the closed end of a cylinder, and acted upon by a piston fitting such cylinder air-tight and carrying a piston rod connected with the self-acting damper. The inventor found the air spring preferable to any arrangement of metal springs.

Let us now see what must be the thickness of the tubes of which the boiler is composed, supposing them to be of good wrought-iron, solid throughout, three inches in diameter, and intended to work under a pressure of 250 lbs. per square inch.

By the formula for cylinders we have

$$t = \frac{p. r.}{10000}$$

$$= \frac{250 \times 1 \cdot 5}{10000}$$

$$= 0 \cdot 0375 \text{ metes}$$

for the best Low-moor iron. Hence we see that this boiler, if made with tubes of which the metal was one twelfth of an inch thick, would be safer from the danger of explosion than an ordinary boiler working at a low pressure—of course, supposing that the hearts be made of ample strength.

The evaporative efficiency of this boiler will of course be improved by the thinness of the metal through which the heat is transmitted from the furnace to the water to be evaporated.

Various kinds of boilers have been proposed and constructed with a view to obtaining the advantages belonging to that which we have just described; but it does not appear that it has yet been surpassed for economy, although its introduction is perhaps retarded by the prejudice existing against the employment of very high pressures in steam-machinery.

We will next proceed to describe types of the most common forms of marine boilers, and for this purpose will select two examples: one, Plate XV., being illustrative of an ordinary flue boiler; and the other, Plate XVI., exhibiting the construction of a marine flue boiler, both being longitudinal sections.

The flue boiler consists of a box-shaped boiler with flat or slightly curved sides, within which is the furnace, having at its posterior extremity a fire bridge, beyond which the flue passes on nearly to the end of the boiler, when it rises and returns along the upper part of the boiler, entering the uptake of the chimney near the front of the same. The steam is partially dried by resting in contact with the casing of the uptake.

The sides of this kind of boiler being flat, necessarily require to be strongly braced by numerous ties, pitched from 14 to 18 inches apart, according to circumstances. The pressure at which such boilers are worked seldom exceeds about 33 lbs. per square inch, and is more generally about 20 lbs. per square inch.

The tubular marine boiler is shown in longitudinal section on Plate XVI. It is similar to the flue boiler in general form; but the large flue is replaced by numerous small tubes, whereby a larger amount of heating surface is obtained. The air required for combustion enters the ash-pit, passes through the fire into the chamber at the posterior end of the furnace, whence it finds its way to the uptake through the numerous small tubes described above.

Locomotive boilers consist usually of two parts, presenting in longitudinal section the aspect shown Plate XXV. The one part contains the furnace or fire-box, which is surrounded on all sides save the bottom by water; ties are used to strengthen the flat sides of the fire-box, and the crown of the same is furnished with ribs.

In designing boilers of any description, care should be taken so to form the various parts that there may be no impediment to the escape of the steam to the upper part of the boiler as rapidly as it is generated; and for this purpose the joints should be arranged so that the recesses formed may not detain the bubbles of steam as they rise; also the sides of flues should not be made vertical, but inclined, so that the water spaces may be somewhat wider at the top than at the bottom.

The manufacture of boilers is very simple. Where it is required to rivet various plates together, they are usually first punched, then placed in juxtaposition and the holes trued by broaching or rhyming them out.

The rivets are made of bar-iron, being formed with one head:

these rivets, when required for use, are raised to a cherry-red or white heat, inserted into their places, and there retained by holding a hammer against the head while the straight end is first hammered up into the form of a head, and then finished off in a conical or hemispherical form by means of swages which are called snaps. The riveting may be done either by hand or by machinery.

The stays are sometimes secured by screwing the ends and fitting nuts upon them; sometimes by riveting and sometimes by screwing and riveting. Riveting may occasionally be employed for securing metal when cold.

The tubes of multitubular boilers may be fixed either by riveting the ends over the tube plates, or by driving in ferules to spread the ends, the apertures in the tube plates being slightly conical; and, lastly, the tubes may be screwed.

Whenever plates intended to be riveted can at all conveniently be drilled, this method of perforation should be adopted, as by punching the metal is strained and the apertures thus produced are not cylindrical; also it is desirable that the plates shall not, when partly riveted together, be forced to fit by driving drifts through the opposite holes, as thereby a strain is thrown upon the shell to which it should not be subjected.

Land boilers are usually set in masonry, and marine boilers in cement.

We have omitted to mention hitherto the appendages which are common to all boilers. These are safety valves, loaded according to the pressure under which the boiler is intended to work; the valve may be acted upon directly by a weight or through the medium of levers, as shown in the illustration, Plate XIII.; or they may be kept down by springs acting through levers, and this is the method commonly used in locomotives.

Steam-pressure gauges are also requisite; they were formerly made of a syphon-formed tube containing mercury, the difference of the heights of the mercury in the two legs of the syphon indicating the pressure of the steam. The most portable and convenient steam-gauge now manufactured is that of M. Bourdon, which consists of a curved tube into which the steam has free access, and the steam by its pressure tends to straighten the tube, this tendency being opposed by the elasticity of the tube. By

means of suitable connections the motion of the tube is communicated to an index placed upon a dial, graduated to show pounds pressure per square inch. These gauges are also made to show vacuums. Gifford's injector is now frequently appended to steam-boilers, to act in place of a feed-pump. In this apparatus a jet of steam passes from the boiler through a mouth-piece, and is partly condensed, when it forces its way through another mouth-piece into the boiler again, carrying with it a quantity of feed-water Its action may appear paradoxical, but is in reality very simple, being as follows.

Suppose the area of the orifice from the boiler to be one square inch, then the steam passing from this aperture with any given velocity, it may be partially condensed without losing this velocity, so that the same amount of energy will be concentrated upon a smaller area; hence, when so partially condensed, it can readily re-enter the boiler and carry other water with it. This apparatus will not act if the temperature of the water be much above 110° Fah.

In addition to the above appendages, man-holes, mud-holes, furnished with doors, and blow-through cocks, are requisite, to allow of the cleansing of the boilers: also guage-glasses to show the level of the water in the boilers.

## CHAPTER XVI.

### ON PROPELLERS.

THE three purposes which propellers are intended to fulfil are, the propulsion of ocean steamers, river steamers, and canal steamers, the latter consisting of tugs only; and the conditions to be satisfied are somewhat different for each class. Ocean steamers, besides requiring efficient power for the arduous work occasionally before them, demand that the machinery should be so placed as to be as safe as possible from enemies' shot; river steamers require to be compact; canal boats must be of light draught, compact, and must have their propelling apparatus of such form as may not cause injury to the banks. For these purposes only two propellers have hitherto been brought into general use, namely, the paddle-wheel and the screw; and to these, and one form of the hydraulic propeller, we purpose now to devote a few brief remarks.

The paddle-wheel, being the longest established, first demands attention. It is manufactured in two forms: paddles with radial float-boards, and feathering paddles. In the first the float-boards are firmly fixed upon radial arms; and in the second they are formed so as to be movable upon an axis, their positions with regard to the horizon being regulated by means of rods, of which the outer extremities are attached, by pins, to arms upon the axes or gudgeons which carry the float-boards, their inner ends being similarly connected with the periphery of a ring fixed somewhat eccentrically to the paddle-shaft. The action of the floats of a paddle-wheel is as follows. Let us direct our attention to one float-board, the engine being at rest and the vessel in still water. Then if the engine be started, a pressure will be exerted upon the water behind the float, which will pass through the water, a certain amount of motion being at the same time communicated to the vessel itself,—the velocity attained being proportional to the pres-

sure existing between the float-board and the water. Now, it is evident that while the float-board is at rest, no pressure is exerted upon the water; but when it begins to move, resistance becomes manifest, such resistance increasing as the square of its velocity; hence if there be any motion of the vessel, there must also be some yielding of the water in a direction opposite to that of the vessel, and if the yielding or part of the yielding of the water takes place in any other direction, there is a loss of power. With the common radial paddle-wheel the water yields in a variety of directions, corresponding with the positions of the various floats at any moment. And besides this, a portion of the water between the float-boards necessarily acquires some centrifugal force, which throws it out from the wheel radially, and thus some energy is wasted in useless work. With the feathering paddles the action is somewhat different from the above; but there exist to some extent the same disadvantages.

The screw-propeller has for some time enjoyed a reputation superior to that of the paddle-wheel, notwithstanding that its use is accompanied by serious disadvantages. In the first place the situation of the screw tends to remove from the stern of the vessel the back water, thereby leaving a deficiency of pressure at the stem of the vessel, which is equivalent to increased resistance at the bows; again, considerable centrifugal force is imparted through the water in contact with the screw, which is accordingly dispersed radially; a corresponding amount of energy being wasted, and at the same time the concussion of such water as passes upwards against the dead wood of the vessel produces vibration. The resistances which a screw has to overcome in a heavy sea are probably on the whole much more uniform than those which are opposed to the motion of paddles, whereby the alternate racing and stopping of the engines are much reduced, but nevertheless, this injurious action exists in a very considerable degree.

The hydraulic propeller has been brought forward at various times in a variety of forms, but hitherto it appears to have failed as a practical propeller. We may instance Ruthven's propeller, also the hirudine propeller. Ruthven's propeller consisted of a fan or rotatory pump, which expelled water through the extremities of channels towards the stern of the vessel. The motion of the vessel was due to the reaction of the issuing jets of water; the

orifices from which these jets proceeded were placed above the water-line, hence the resistance offered to the exit of the water was that due to the pressure of the atmosphere; it is therefore not difficult to imagine that this propeller proved useless as an economical means of obtaining motion. If the orifices mentioned above be closed, the pump may, nevertheless, be worked, and it will in such case impart only a whirling motion to the contained water; whence it appears that this propeller admits of the engine being driven without producing any useful effect.

The hirudine propeller consisted of a tube in which was a diaphragm, so formed that by means of vertical rods a wave was produced in it passing backwards, thereby carrying the water from the bows of the vessel and expelling it at the stern, so as to impart to the vessel a forward motion by the reaction of the water thus ejected,—the action of course being intermittent, the water passing through the tube in waves. This apparatus appears to present fairer prospects of success than that last described, but it is many ways complicated and inconvenient. The name was given on account of some supposed resemblance to the action of a leech, though the true principle of the propeller can scarcely be regarded as analogous to the principle of propulsion exhibited by the leech.

The two propellers above described possess the great advantage of acting only in that direction in which the greatest effect is produced, namely, in a direction parallel to the vessel's course; whereas the paddle-wheel only acts in this direction in one position, and then also imparts centrifugal force to the atoms of water with which the float board is in contact, and this force is also produced by the screw-propeller.

Neither Ruthven's nor the hirudine propeller has come into use, but of the two we think the latter the best, as the resistance of the water is employed instead of that of the atmosphere, while the parallel action of the propeller is retained.

More recently this same principle has been adopted in an ingenious apparatus designed by Mr. C. G. Gumpel, and patented by him a short time since. Plate XVII. shows various views of the apparatus alluded to. Beneath, or flush with the level of the bottom of the vessel, is placed a rectangular channel, running fore and aft, and expanded at the centre into a large chamber, above

which are placed two cylinders, fitted with water-tight pistons. If we suppose one of these pistons to ascend, water will evidently enter the channel and fill up the cylinder beneath it, following the piston as it rises, and its descent will of course be accompanied with the expulsion of the water beneath it; and the action of the apparatus is such, that when one piston is ascending the other is descending, a regulating valve being introduced in the large chamber mentioned above, which so acts that the water passing through the propeller enters at the fore-end of the channel, and passes out at the after-end,—the orifices through which it passes being capable of a variation of area to suit the velocities at which it may be desired to propel the vessel. In the Plate, Fig. 1 represents a longitudinal section, and Fig. 2 a plan of the apparatus. A B is the channel, C D are the pistons, E E the regulating valve, shown in position suitable when C is ascending and D descending; on the contrary, *k b* shows the position of the valve.

It would be premature to advance any decided opinion on the practical utility of this invention; but the author can testify to the satisfactory results of numerous experiments tried with a small model at various times and under a variety of adverse circumstances.

# CHAPTER XVII.

## ON VARIOUS APPLICATIONS OF STEAM-POWER, AND APPARATUS CONNECTED THEREWITH.

In the foregoing chapters we have treated especially of those forms of machinery and processes which are of common application, in which, however, numerous applications of steam-power and appendages to prime movers have of necessity been passed over; wherefore, the following pages will be devoted to the consideration of some of the subjects previously omitted.

We will commence with stationary engines. Of these the pumping engines appear to be the first found of practical utility, and even at the present day the Cornish pumping engine of 1835 is scarcely surpassed in point of economy; but the improvements suggested by Mr. Wicksteed in adapting the pump-work to water-works purposes, and other improvements of less importance, have produced a greater economy, as is clearly shown in the comparison of long working of the two engines at the East London Water-works as compared with the two best engines in Cornwall. (See "Further Elucidations," &c. Weale, 1859.)

It may be interesting here to pause for a moment to compare the economy of engines built twenty years ago with those of the present day; but we are at once confronted with a difficulty not easily surmounted, namely, the want of *reliable* experiments. Experiments, it is true, are recorded in sufficient number, but the reliability of many of these is indeed very questionable, for they are usually continued for about twenty-four hours or less, and the results of this short working, if considered favorable, are then reported. The inutility of such trials is sufficiently evidenced by the table on page 5 of Mr. Wicksteed's "Experimental Enquiry," published in 1841, which shows the results of short trials upon the same engine with coals taken from the same heap; the minimum duty produced by 94 lbs. of coals was 63,650,298 ft.-lbs.,

and the maximum duty reached 118,522,475 ft.-lbs., or nearly twice the minimum duty.*

The existence of such facts as these will naturally make those interested in the economy of steam-power careful to know the circumstances under which engines are experimented upon, to avoid the disappointment of finding the working economy of steam-power far inferior to that deduced from experiments. The only cases which can be quite satisfactory to the practical man are those where *all* the particulars of the trials are published; such, for instance, as quantity of water evaporated, duration of trial, state of fires, &c., &c.; the duty given *alone*, without any account of the evaporative value of the fuel used, being almost useless. Suppose, for instance, the consumption of fuel only in the "Thetis" and "Inca" during the experiments published some time since, be taken into consideration, it will give a vast superiority to the former, whereas, when allowance is made for the different evaporative values of the fuel employed, the difference of economy in the two vessels is small. The only trials with which we are acquainted which supply all that can be desired, are those published in the "Experimental Enquiry" alluded to above, and we are further strengthened in the opinion that no others are extant from the remarks in Bourne's "Treatise on the Steam-Engine," new edition, page 110, which are as follows. Having reference to the comparison of theory with experiment Mr. Bourne says:—"In order to test the practical value of this theory, it will be useful to compare its results with those of the experiments which were made by Mr. Wicksteed on the large Cornish pumping-engine, built under the direction of that eminent engineer by Messrs. Harvey and West, for the East London Waterworks, at Old Ford, and

* This opinion is completely corroborated by the following statement of the duty done by the Fowey Consols engine at the well-known trial in 1835, which was so far superior to that during the working of the same engine for long *periods*. (*See* "Further Elucidations," p. 14.)

| | | | |
|---|---|---|---|
| *At* the twenty-four hours' trial . . . | 134,100,000 ft.-lbs. per cwt. | | |
| *Highest* duty in any one month during eleven years . . . . . . . . . . | 99,422,891 | " | " |
| Average duty for the year 1835 . . . | 86,446,269 | " | " |
| The month before the trial . . . . | 93,034,325 | " | " |
| The month of the trial . . . . . . | 94,912,548 | " | " |
| The month after the trial . . . . . | 97,559,843 | " | " |

which were published in 1841. The dimensions and structure of the engine and the details of the experiments are stated with such minuteness and precision that there is none of that uncertainty respecting the circumstances of particular cases which is the most frequent cause of failure in the attempt to apply theoretical principles to practice."

We have dilated somewhat upon this subject, as it is of vital importance to the progress of steam-engineering to be acquainted with the actual success or otherwise of the various forms of steam-engines. In 1859 Mr. Wicksteed published an account of the duty of the "Wicksteed" engine at the East London Waterworks, obtained from *three* years' working, which of course can leave no doubt upon the mind as to reliability.

We will now compare, as far as our means will allow us to do so, the results of certain pumping engines.

From Mr. Wicksteed's experiments (1841) we find that a duty of 108,198,102 ft.-lbs. per cwt. of fuel was obtained on a long trial of the Cornish engine of the East London Waterworks; 122,376,128 ft.-lbs. at the trial of the Holmbush engine; 130,248,384 ft.-lbs. at the trial of the Fowey Consols engine. From the working of the "Wicksteed" engine for three years, a duty of 109,000,000 ft.-lbs. is obtained, for best Welsh coal. (See Mr. Wicksteed's pamphlet, "Further Elucidations," &c., 1859.)

As a specimen of more recent construction, we may refer to an engine erected for the Chelsea Waterworks' Company, and reported upon by Mr. Joshua Field, April 9th, 1857. The trial, as reported, lasted for 24 *hours only*, and a duty of 103,900,000 ft.-lbs. per cwt. of coal was obtained.* This result shows not only an absence of improvement, but an inferiority to the above-mentioned engines, which might scarcely be expected when we view the general improvements effected during the last twenty years. The Cornish engine above referred to was constructed about 1835.

In the Cornish engine the motion of the plunger-pole is controlled only by the internal resistance, the plunger-pole of the pump being suspended from the end of the beam, and no fly-wheel being employed. Recently, fly-wheels have been applied to pumping engines, but without producing satisfactory results.

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* Mr. Field's Report; Bourne's Treatise, Appendix.

Formerly, beam engines were universally employed to drive mill work, when large power was required; and in fact Newcomen's type appears to have formed the basis of all the earlier engines; beams being used for marine engines also. The advantages attendant upon more compact forms of machinery did not long remain unobserved, and recently beam engines have been almost entirely superseded by direct action engines for marine purposes, where economy of space is a desideratum. A great many of the improvements effected in the construction of stationary or land engines have arisen not so much from the necessity of improvement in this one class, as from the restrictions under which the engineer acts when designing steam-machinery for marine and locomotive purposes. The difficulties attendant upon the adaptation of steam-power under the circumstances last referred to necessarily increase in proportion as the space at command diminishes; wherefore the engines of the small river steamers are generally more compact in form than the bulky machinery of the larger steamers.

Among the particulars not hitherto specially entered into we may mention various contrivances for facilitating the consumption of the smoke,—the principle of them being in itself exceedingly simple, as all that is necessary in order to ensure the consumption of the smoke is, to mix a sufficient quantity of atmospheric air with the same, at a temperature not lower than that at which the gases burn. Notwithstanding the apparent simplicity of this operation, the means of carrying it into practice do not readily present themselves, as appears evident from the great number of methods which have been proposed to obviate the nuisance and waste given rise to by the evolution of smoke. Prideaux's furnaces appear, upon the whole, to be best calculated to effect the desired end with economy; but one of the chief requisites to smoke consumption consists in properly managing the fires.

Another source of economy which has lately been much used consists in superheating the steam; that is to say, imparting to it a temperature higher than that due to its pressure; thereby avoiding, in some degree, condensation in the steam-cylinder. The steam may be superheated by contact with hot flues passing through the steam space of the boiler, or the steam may be

caused, in passing from the boiler to the engine, to traverse pipes placed in the uptake of the chimney-shaft or passing through the furnace. The introduction of superheated steam has, in some cases, been found useful in the absence of the steam-jacket, which consists of an outer cylinder or jacket placed around the working cylinder of the engine, the small annular space left between the two being kept full of steam from the working boiler, or from a separate boiler. Sometimes the steam-jacket is replaced by a hot-air jacket, and in every case, whether the cylinder be jacketed or not, it should always be well clothed, to avoid the radiation of heat from its surface into the surrounding air. Clothing should also be applied to the boiler and steam-pipes, and in some cases a very great amount is requisite; such, for instance, as that of the locomotives designed to traverse the ice in the frozen regions of Siberia. Under these circumstances, thick coatings of felt, covered with coatings of wood, may with advantage be employed, the cylinders being similarly protected. Loss of heat from the sides of flues of stationary boilers may be much reduced by leaving an air-space around them, completely closed in by masonry, so that the air cannot circulate. It is frequently necessary to supply the stationary and other boilers with small feed-pumps, which may be worked by hand or by donkey-engines.

Large marine-engines are also very commonly supplied with small steam-cylinders to work the starting-gear.

The means of ascertaining the amount of duty obtained from rotating engines are very insufficient, the indicator and the friction-brake being most commonly used. The indicator consists of a small brass cylinder, furnished with an accurately-fitting piston, capable of moving steam-tight, but with very little friction; this piston, when unacted on by any other force, is retained at the lower end of the cylinder by a spiral-spring above it. It carries a piston rod, to which is attached a pencil-holder, which, when the instrument is required for use, is furnished with a pencil, the point of which rests upon paper, which is caused to move under it in a direction at right angles to the axis of the cylinder of the indicator. the motion being derived from some part of the engine. If this indicator be attached by its lower extremity to the cylinder of the steam-engine, it is evident that when steam enters the working cylinder, the indicating piston will rise, compressing the

spring above it, the amount of compression being proportional to the pressure of the steam, and as the engine moves the card also moves under the pencil; thus a diagram is obtained, showing the pressure of steam in the cylinder at every part of the stroke of the engine, and from such a diagram, the mean pressure of steam in the cylinder during one stroke may readily be calculated. The horse-power calculated for this mean pressure is called the indicated horse-power.

The friction-brake in its common form consists of a band containing wooden blocks, which is placed around the main shaft of the engine, and tightened up until the same is brought to its accustomed speed; then, from the extremity of an arm fixed to the band, weights are suspended until the arm remains horizontal. The amount of work done by the engine in any given time is calculated by multiplying the weight attached to the brake by the distance of their point of suspension from the centre of the main shaft, and by the number of evolutions of the same.

Steam carriages and traction engines for common roads have lately attracted much attention, and many ingenious forms have been designed and executed, and frequently exhibited in the metropolis; and for some time past, Bray's traction engines have been much used. These engines are not intended so much for speed as to draw heavy loads at a small cost; hence, gearing is employed to produce the speed of the engine,—toothed wheels being sometimes employed, and sometimes chains. With the former some inconvenience is found, when running on rough roads, from the variation of distance between the toothed wheels, which of course interferes with their smooth action. In Messrs. Longstaff and Pullan's engine, the cylinder and its attachments are placed upon frames capable of moving upon an axis, so as to allow the driving-wheel to rise and fall over the inequalities of the road without affecting the distance between the centres of the toothed wheels.

A very light form of steam-carriage has been designed for common roads by Messrs. Yarrow and Hilditch, in which arrangements are made to prevent the action of the springs to which the driving-wheels are attached from interfering with the motion of the slide-valve; but the absence of horn plates allows lateral strain

of the piston rod, &c., and until this is supplied the action of the machine cannot be relied upon.

We have now concluded the few remarks which appeared desirable to render the previous descriptions more complete. It would be utterly impossible, in ordinary limits, to notice one tithe of the various forms in which the steam-engine exhibits itself, but we have endeavored to select examples as general as possible.

# CHAPTER XVIII.

## ON PUMPING ENGINES.

There is, perhaps, no method of imparting information practically more effective than that which is based upon the illustration of good examples, which show at a glance the manner in which scientific principles are rendered available for the daily purposes of mankind; and such a treatise as the present would certainly be very incomplete without some detailed account of the present practice.

We have selected, in order to exemplify the most useful forms of pumping engines, two erected by Mr. Wicksteed, through whose courtesy we are enabled to supply the plates and description of the same.

Plates XVIII. and XIX. illustrate the Grand Junction engine, erected at the Grand Junction Waterworks, at Kew. It is constructed on the same principle as the celebrated "Wicksteed" engine, subsequently erected at the East London Waterworks, and was executed by Messrs. Sandys, Carne, and Vivian, the contract being dated 1845.

Plate XVIII. shows a general elevation of this engine. *a* Is the steam-cylinder, which is surrounded by jacketing and clothing: *b* is the valve-casing and framing for valve-gear, which gear is actuated by tappets on the plug rod *c*; *d* is the piston rod, the upper extremity of which is attached to a parallel motion, *e f, g h, j*, of which the centres *e f g* and *h* are movable, the centre *j* being fixed; this parallel motion is joined at *g h* to the main or working-beam, and to that extremity of the latter to which the parallel motion is attached, is fixed a catch-beam *k*, to prevent the piston from descending too low. The main beam is supported at the centre of its length upon a gudgeon resting in bearings carried by an entablature supported upon columns, as shown.

Passing from the main centre just described, we first come to a rod, by which the feed-pump *l* is worked. The motion of this rod is rendered nearly rectilineal by connecting it with a parallel motion which extends to the end of the beam, and to which is attached the rod actuating the air-pump *m*. From the end of the beam the plunger-pole *o* is suspended, which works vertically in the barrel of the main pump, *p*; upon this plunger-pole is fixed a table, carrying weights, which are enclosed in the casing *w*; *n* is the hot well placed above the air-pump *n*, and it is from this hot well that water is drawn by the feed-pump *l* to supply the boiler which furnishes the engine with steam. *r* is the eduction-pipe leading from the cylinder to the condenser, which, together with the air-pump, is placed in the cold-water well. In addition to the details shown in the elevation, there are two cataracts,—one on either side of the valve-gear. The general arrangement of the engine having been now explained, we will proceed to describe each part in greater detail.

The cylinder is bedded upon a mass of masonry, to which it is secured by six long holding-down bolts, furnished with nuts at their upper extremities and fixed at the lower by washers and gibs. These bolts are about two and a half inches in diameter, and descend through masonry to a depth of about fourteen feet. Upon the masonry rests the casing of the cylinder-bottom, the total height of which is about two feet, and it is upon the lower flange of this cylinder-casing that the hollow struts are placed to receive the upper extremities of the holding-down bolts. These struts are two feet eight inches high from the floor, and the thickness of the metal is one and a half inches at the lower part, reduced to one-and-a-quarter at the upper. The casing for the cylinder-bottom consists of a short cylinder cast in one piece of the cover, which is convex downwards, and it is closed by a loose bottom,—the space between the top and bottom of this casing, inside, being at the centre about seven inches and a half, and at the circumference about eighteen inches. Upon this casing rests the cylinder, of which the internal diameter is about seven feet six inches: the thickness of metal being about one inch and three quarters. Round the cylinder is the jacketing, between which and the cylinder a steam-space is left; and the flanges of the casing for the cylinder-bottom and the cylinder and the jacket, are all bolted

together, forming a joint, shown Fig. 90, which is drawn to a scale of one inch to a foot. Outside the jacketing is an air space, surrounded by timber clothing. Similar precautions to those described above for preventing loss of heat are observed in the

Fig. 90.

construction of the cylinder-cover, through which the piston rod passes, steam-tight, by means of an ordinary gland. The diameter of the piston rod is about eight inches.

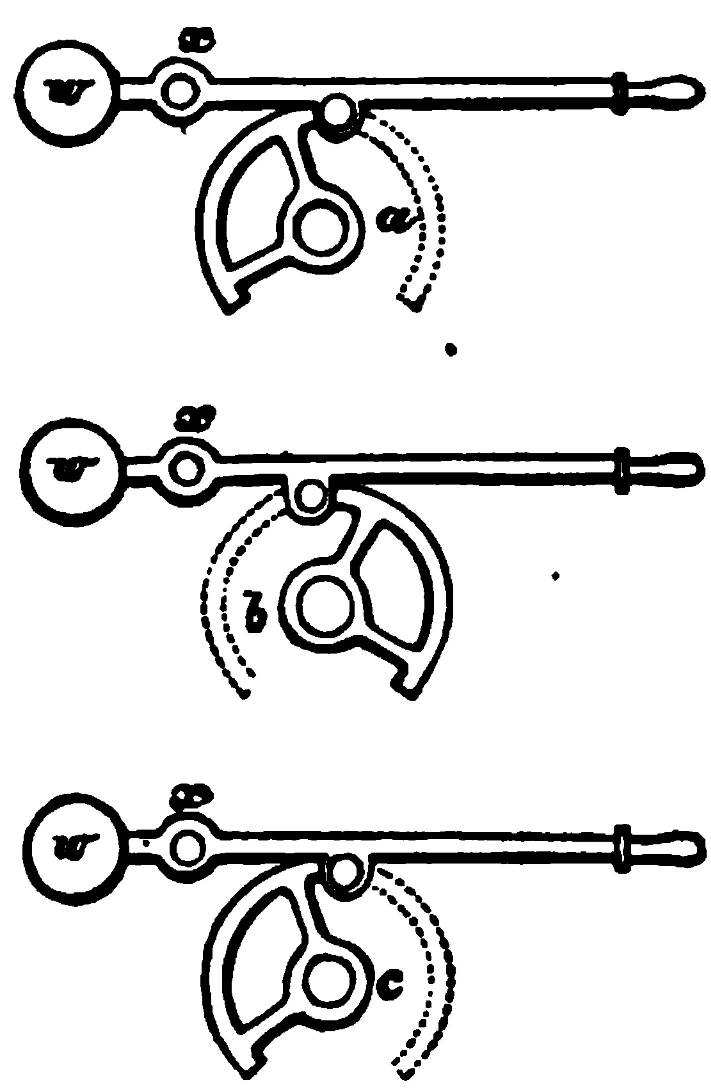
In order to render evident the arrangement of the valves and valve gear, we must refer to Plate XIX., in which two elevations of the gearing are shown. A glance at the front elevation of the valves shows that four are supplied: they are double-beat valves, having the top and bottom beats of equal diameter, three being placed at the upper end of the cylinder, and one at the lower. The three upper valves are, the starting-valve, the steam-valve (through which steam is admitted to the upper extremity of the cylinder), and the equilibrium-valve (through which steam passes from the upper to the lower side of the piston). The lower valve is the exhaust, through which the steam passes from the lower side of the piston into the condenser. To each of the three upper valves is attached a stem, passing through a stuffing-box and through a guide; this stem is acted upon by the short end of a lever, the position of which is indicated by the dotted lines. From the longer end of the lever a rod descends, of which the lower extremity is attached to an arm carried by one of the weigh-shafts of the valve gear; the arrangements being such that, when the valve rods and the arms to which they are attached are in the same straight line, the valves are closed. The exhaust-valve is

similarly actuated; but in this case the lever to which the valve rod is attached is bent. In connection with the valve gear are three weigh-shafts,—the upper one being connected with the steam-valve, the centre one with the equilibrium-valve, and the lowest with the exhaust-valve. The three weigh-shafts, which we shall designate the steam, equilibrium, and exhaust-valve shafts, are marked *a*, *b*, and *c*, respectively, in both views. To these shafts are keyed arms, *a d*, *b e*, and *c f*, from the extremities of which rods are suspended, connected at their lower ends with cast-iron balance-levers, to which are hung weights. The tendency of these weights is to open all the valves. Another set of arms is also attached to the weigh-shafts, by means of which the valves are closed: these arms or handles are shown in both views at *a g*, *b h*, and *c i*. It will be observed that the weight in connection with the shaft *a*, when descending, opens the steam-valve and causes the arm *a g* to rise to the position shown in the dotted lines. The weight connected with the shaft *b*, in descending, opens the equilibrium-valve and throws the handle *b h* down to the position shown by the dotted lines, and the weight acting upon the bottom shaft opens the exhaust-valve, and raises the handle *c i*; hence we see that the valves are opened by the descent of the weights. We must next observe the means of closing them. The plug-frame consists of two rods, *m m*, *m m*. These rods carry tappets, *k*, *l*, and *n*. Let us suppose that the engine is about to make a down-stroke: then the arms *a g* and *c i* will be in their highest positions; as the plug-rods descend the tappets *k* will strike the arms *a g*, and depress them, thereby closing the steam-valves and raising the balance-levers connected with the shaft *a*, and subsequently the tappet *l* strikes the arm *c i*, closing the exhaust-valve and raising the balance-levers connected with the shaft *c*. These arms, thus depressed, are retained in the position into which they are thrown by means which will subsequently be described.

When the engine is about to make an up-stroke, the arm *b h* is in its lowest position, the equilibrium-valve being open. During the ascent of the plug-frame the tappet *n* raises the arm *b h*, closing the equilibrium-valve, and raising the balance-lever connected with the shaft *b*, this position being retained by means of a catch. It is now necessary to explain the manner in which the catches

act; and in this we shall be assisted by the woodcut, Fig. 91, in which *a*, *b*, and *c* are the three weigh-shafts, to which are attached quadrants, as shown, being fixed at the ends of the shafts. When the handles are acted upon by the tappets, the shafts revolve so that the quadrants assume the positions shown in the woodcut, in which they are retained by the pins attached to levers, moving upon fulcra, *x*, *x*, *x*, and equilibriated by weights *w*, *w*, *w*. If the

Fig. 91.




catches be raised the balance-levers cause the quadrants to assume the positions indicated by the dotted lines, the pins in the catch-levers then resting upon their peripheries. The extremities of these catch-levers are shown (Plate XIX.) at *a′b′c′*. We have now shown how the valves are closed, and retained closed, but it yet remains to show how the catches are raised to allow the balance-levers to open the valves. This is effected by cataracts, of which there are two, shown at *o o*, Plate XIX. These cataracts are species of pumps, fitted with a solid plunger packed with leather. Their action is as follows: Upon the plug-rods *m m* are fixed tappets *p q*, which act upon levers *p r* and *q r*. During the down or indoor-stroke, the tappet *q* depresses the end of the lever *q r*, winding the band *s* around the pulley *t*, and drawing down the end *u* of the rocking-beam *u v*, and elevating, therefore, the end *v* of the

beam; at the same time drawing down the rod *u u* and pushing up *v v*, thereby raising the plunger of the cataract, which as it rises draws water freely through a valve from the cistern below it; then the weight on the plunger-rod of the cataract, together with that suspended from the end *v* of the beam, causes the plunger to descend, forcing out the water from beneath it, through a stop-cock, back into the cistern from whence it was taken,—the velocity with which the plunger descends being regulated by the opening of the cock. In concluding its down-stroke, the cataract by means of the rod *u u*, releases the catches on the top and bottom weigh-shafts, thereby allowing the balance-levers to open the steam and exhaust valves, when the engine will make another down stroke. The cataract on the opposite side of the engine is raised during the up-stroke, and releases the catch on the shaft *b*, to allow the equilibrium-valve to open to cause the next up-stroke. The amount of waterway allowed by the cataract-cocks determines the time which elapses between two strokes, and thus the speed of the engine is regulated. The position of the tappets *k k*, which close the steam-valve, admits of adjustment by means of the screw *y*, and upon their height with regard to the plug-rod depends the point of the stroke at which the steam will be cut off. Their length is necessary in order that they may hold the handles *a g* down until the cataract which governs the catches *a′ c′* has been raised so as to allow the catch *a′* to secure the steam-valve. We have very minutely described the form and action of the valve gear of this engine on account of its complicated character, in order to leave no means unemployed by which it could be explained, as it is highly important clearly to understand this beautiful part of the mechanism of the engine, upon which its action is dependent.

The parallel motion is formed of bars, carrying brass bearings in the usual manner. The main beam consists of two beams braced together, its length from cylinder centre to the pump centre, is thirty-six feet eight inches, each of these centres being eighteen feet four inches from the centre of the beam; the depth of the beam at the centre is about seven feet six, and at the extremities about two feet eight. The two beams are braced together by six ties, one and a quarter inches in diameter, of wrought-iron, passing through distance-pieces eight inches in diameter; the two pieces

of the beam are about three feet four inches asunder, the metal three inches thick, and the main gudgeon one foot four inches in diameter. The distance from the cylinder centre along the beam to the first parallel motion centre, is eight feet four inches, and to the plug-rod centre, ten feet four inches,—the latter being eight feet from the main centre of the beam; the feed-pump centre is four feet seven inches from the main centre, and the air-pump centre ten feet,—the latter being eight feet four inches from the main-pump centre. The parallel motion for the main pump is similar to that for the piston rod; the diameter of the main-pump rod is eight inches, that of the casing containing the weights is five feet eight inches outside, and five feet five inches, its height being eight feet four inches. Below the casing is another, carrying two bracket-shaped projections or snugs of three-inch metal, which, by falling upon spring beams at the termination of the outdoor stroke, support the plunger-pole and weights. The plunger is hollow, its external diameter being two feet nine inches, and its internal diameter about two feet three inches; the pump barrel is about three feet in diameter, its metal being two and an eighth inches thick. The valves are on the principle of Messrs. Harvey and West's double-beat valve, the lower seating being two feet ten and a half inches in diameter, and the upper beat two feet three and a half inches; a collar prevents the valve from rising too high, the collar itself being retained by a three-inch rod, screwed through the top of the valve chamber.

Both the valve chambers are four feet three inches in diameter, the depth of the tank around them is about seventeen feet two inches, the bottom of the tank is of two and three-quarter inch metal, the sides at the lower part of three-quarter inch metal, and at the upper of five-eighth inch. The valve chambers are two and an eighth inches thick, the water from the discharge valve passes through a three-foot pipe to the stand pipe, the plate with which it is connected being one inch thick. The spring beams on each side of the plunger each consist of seven beams, fifteen inches wide and six inches deep, with a bearing between the supports of about six feet nine inches, the supports consisting of hollow columns of two-inch metal. The distance between the spring beams on the two sides is six feet nine inches, the anchoring girders for the parallel motion are eighteen feet long, one foot six inches deep, and

one foot ten inches deep over the points of support; they are cast-iron trellis girders of one and a half inch metal in the webs, the centre to which the parallel motion is anchored is five inches diameter and three at the extremity, and the distance between the parallel motion bars is seven feet four inches. The outside diameter of the exhaust pipe is about one foot ten, of the condenser about three feet six, and of the air-pump about three feet three. The action of the engine is as follows: Suppose the engine to be at the top of its stroke, then, when the cataract which governs the steam and exhaust-valves descends, the catches will be released and those valves will open, when a down-stroke will be made, during which the same cataract will be raised and the steam and exhaust-valves closed,—and at the same time the plunger will be raised, filling the pump barrel with water; the air-pump will also draw a certain quantity of water from the condenser. The engine will then pause until the other cataract releases the equilibrium-valve, when the weights on the plunger-pole will cause it to descend, closing the equilibrium-valve, raising the second cataract, and drawing the piston to the top of the cylinder,—the air-pump bucket being depressed so that the water, &c., drawn from the centre during the up-stroke of the pump, passes through the bucket, the water in the main pump being at the same time expelled through the discharge-valve. It must here be observed, that in the Cornish pumping engines the injection cock, which admits condensation water, is not constantly open, but is opened by the valve gear, and remains closed during the outdoor stroke.

This description applies to the engine as originally erected, but now the pump plunger is being enlarged; the intention being, I believe, to work with steam of higher pressure. Before taking leave of the Cornish engine it may be desirable to give some account of its management. When it is desired to start an engine after it has been at rest for some time, it is necessary to work it for a few strokes by hand, and at first it will fail to complete the indoor or down-stroke of the piston on account of deficient vacuum, wherefore the exhaust-valve will not be shut by the tappet, which will not reach it. The equilibrium-valve is now gradually opened, and the engine goes slowly out of doors: when the equilibrium-valve is closed, first the exhaust and then the steam-valve is allowed to open, and so on, until the engine assumes its proper

stroke. Any variation of the steam pressure will of course be accompanied by varying strokes, but this must be counteracted by working the governor valve; and the length of stroke may be accurately judged by observing how far the tappets travel along the handles after closing the valves. It will from the above be evident that these engines require constant attention, as otherwise they might miss stroke if the steam fell short; when the steam stroke is too long, catch-pieces strike upon the banging-boxes, and ring a bell to call the engineman's attention to the fact.

In the new pumping engine which is now in course of erection at the Scarborough Waterworks, under Mr. Wicksteed's superintendence, surface-condensation is employed. This is, we believe, the first application of a surface-condenser to a Cornish pumping engine.*

In the ordinary Cornish engine only one cataract is used, and the plug-rod in descending shuts the steam and exhaust-valves, and releases the equilibrium-valve; hence, there is no pause between the down-stroke and the up-stroke, and the injection-valve is also wrought by an arm attached to the exhaust-valve weigh-shaft.

Our next example is the Boulton-and-Watt pumping engine erected at the East London Waterworks, under the superintendence of Mr. Wicksteed. Plate XX. is a longitudinal section of the engine. It will be observed that a piston-pump is here employed, the water being drawn into the pump-barrel during the up-stroke of the steam-piston, and forced into the mains during the down-stroke of the same. This is the principal difference between this and the Cornish engine, but the details of the two engines also differ. It will not, however, be necessary here to give a complete description of this engine, as from our previous remarks the section will be readily understood, and will give all the informa tion that is requisite.

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* We are not at liberty to give any particulars of this condenser, as Mr Wicksteed is, we believe, about to publish an account of the new engine at the Scarborough Waterworks in a treatise on Pumping Engines, which will shortly appear.

## CHAPTER XIX.

### ON ROTATIVE ENGINES.

In the present chapter we propose to illustrate two rotative engines, one of which is a beam engine, and the other a horizontal engine on Woolfe's principle, used for pumping.

Plate XXI. is a longitudinal section of a beam-engine; the cylinder is cast with the bottom upon it, in the centre of which is left an aperture to admit the boring-bar, this aperture being subsequently closed by a door, as shown. The upper end of the piston is attached to an ordinary parallel motion, jointed to the main beam, which beam is carried by a gudgeon working in bearings supported by a large hollow column; beyond this gudgeon the air-pump rod is attached, and at the farther end of the beam is the connecting rod, the lower end of which embraces the crank-pin. The crank is firmly keyed on to the main shaft, which also carries a fly-wheel and the eccentric, by which the short slide-valve, which regulates the admission of steam to and its emission from the cylinder, is worked. A common two-ball centrifugal governor is applied to this engine.

The usual cold-water and feed-pumps are also applied. It will be observed that the column supporting the entablature to which the parallel motion is anchored, is secured to a thick lug cast on to the cylinder. This, however, should be avoided where possible, as inequalities in the thickness of a casting are very likely to produce defects.

It will be observed that the cylinder of this engine is neither clothed nor jacketed, whereby economy is lost; for both these precautions should be adopted, especially when superheating is not resorted to.

Plate XXII. exhibits a longitudinal section of a horizontal pumping engine on Woolfe's principle. At the extreme left-hand corner is placed the pump, which is double-acting. From

the well rises a vertical pipe, leading into a horizontal pipe, passing in both directions, and having its ends curved at right angles, and surmounted by spindle-valves, which are the suction-valves of the pump. From the upper side of the pump, tubes proceed into a horizontal pipe, and where they join the same the discharge valves are placed. Upon the upper horizontal pipe is placed the air-vessel, to equalize the pressure of the water and prevent the occurrence of shocks. To the plunger of the pump is attached the pump-rod, which terminates in a cross-head, carrying guide-blocks, moving between guides. To the same cross-head is fixed, by a cotter, a piston rod, the further extremity of which is connected to the piston of the larger cylinder, shown in the drawing. Abutting upon the larger cylinder and concentric with it, is the smaller cylinder, and upon the two cylinders is placed the slide-valve and steam-chest, with various passages proceeding from it. The smaller cylinder contains a piston, the rod of which is connected with a cross-head, from which proceeds a connecting rod to work a crank fixed upon the main shaft of the engine, which main shaft carries a fly-wheel and an eccentric, which works the slide-valve. To the cross-head last mentioned is attached a link, through which is wrought a bell-crank, having a long vertical and a short horizontal arm. From the short-arm links are carried up to work the air-pump, upon the top of which is placed the hot well, from which water to feed the boiler is drawn by the horizontal feed-pump, shown to the right of the air-pump, and worked by a link attached to the long arm of the bell-crank. On the left of the air-pump is the condenser, with the exhaust-pipe entering at its upper extremity. The round opening shown in the condenser indicates the position of the injection-cock.

The action of this engine is as follows: High-pressure steam from the boiler is admitted to the small cylinder, and when the small piston has made one stroke the steam is allowed to escape into the large cylinder, and act by expansion, the communication with the boiler being at the same time cut off, and from the large cylinder the steam passes to the condenser. In order that the pistons may work together, the steam which enters the inner end of the small cylinder passes thence to the inner end of the large, and *vice versa*. The action of the pumps is thus: When the air-

pump bucket rises, condensation water is withdrawn through the foot-valve of the condenser, and on the descent of the bucket the water beneath it passes through the circular-valve, which moves upon the air-pump rod; and when the bucket rises, this water is expelled through the circular valve which covers the air-pump into the hot well, whence a portion of it is drawn by the feed-pump, which is of the plunger description. The excess of water passed into the hot well escapes through a waste-pipe. The condenser and air-pump are placed in a cold-water cistern.

We have given this as a good example of a Woolfe engine, although, considered as a pumping engine, it is certainly very inefficient, being very inferior (as are all rotative engines) to the Cornish engine, when applied to raise water.

## CHAPTER XX.

### ON MARINE ENGINES.

THE variety of engines used for marine purposes appears to be more extensive than that of any other class, designs innumerable having been originated for screw-propeller engines. Those used for paddle-wheel steamers do not vary so much in design.

Plate XXIII. is a longitudinal section of a side-lever marine engine of the old class.

*A* shows that end of the sole-plate to which the cylinder is bolted; *B* is the working cylinder, furnished with a piston *C*, rendered steam-tight by metallic packing. To this piston is attached the piston rod *E*, which passes through a stuffing-box in the cover *D* of the cylinder; the top of the piston rod carries a cross-head, which is secured to it by a gib and cotter-joint; from the extremities of the cross-head links descend, being jointed at the bottom to the side-levers, of which there are two, one on each side of the engine. These side-levers are similar in form to the working-beam of an ordinary beam engine. One of the side-levers is shown partly dotted, and the link which connects it with the cross-head of the piston rod is also shown dotted. *R* is a parallel-motion link which is attached to a short arm *S*, to which motion is imparted by a link jointed to the side-lever. Those extremities of the side-levers which are distant from the cylinder are attached by gudgeons to a cross-tail, keyed to the lower end of the connecting rod *G*; the upper end of the connecting rod carries bearings, retained in position by a strap secured to the connecting rod by a gib and cotter joint. These bearings embrace the crank-pin, the crank being keyed on to the main shaft *H*. Close behind the crank the main shaft is supported in bearings carried by a plummer-block, bolted to the framing. Behind the plummer-block is the eccentric, from which a trussed rod passes to a short arm on the weigh-shaft *T*, which carries a double arm, from one end of which the slide-valves

are suspended by a rod *U*, a counterbalance being placed at the other end of the double arm. The valves are of the *D* form, having packing behind them.

The steam having been admitted to the cylinder, and having caused the piston to make one stroke, it passes through the upper or lower passage, as the case may be, into the condenser *N*, where it is condensed by a shower of water passing through the injection cock, regulated by the handle *F*. The condensed steam and the vapor are subsequently withdrawn through the valve *L* into the air-pump *I*, during the ascent of the air-pump bucket *J*, which is worked by a pump rod *K*, carried by a cross-head, connected by side links with the side-levers. On the descent of the pump-bucket, the water &c. beneath it passes through the annular valve around the pump rod; and when the bucket again ascends, the water &c. upon it is expelled through the clack-valve *M* into the hot well *P*, whence a portion of it is drawn by a feed-pump to supply the boiler, the rest passing out through the ship's side. *Q* is an air-vessel to prevent shocks. The air-pump barrel and rod are lined with brass, so that they may not be acted upon by the injection-water. The passage leading from the condenser to the air-pump is continued beyond it, terminating with a chamber fitted with a shifting valve. There are also furnished bilge pumps worked by the side-levers, but not shown in the Plate.

It will be observed that in this engine care is taken that the injection water should not strike against the sides of the vessels unnecessarily; and this is a point worthy of attention, as a jet of water striking an iron plate will not fail to reduce its thickness.

Plate XXIV. represents an elevation and section of a direct-action screw-propeller engine: the air-pump and the cylinder on the right-hand side of the plate being shown in section. The cylinders are placed in a horizontal position, one on either side of the main shaft. Their diameter is very great in proportion to their stroke. The slide-valves are short, being enclosed, as usual, in a steam-chest or slide-jacket. Stout piston rods pass through stuffing-boxes in the cylinder-covers, and terminate in guide-blocks moving between stout horizontal guide-bars. The guide-blocks are attached to short connecting rods, which act upon the crank of the main shaft. Each slide-valve has a pair of eccentrics and a link to work it similar to those of a locomotive, one being so fixed

as to drive the engine forward, whilst the other is adjusted to drive it backward. This link is raised and lowered when necessary by means of a rack and pinion worked by a hand-wheel. The air-pump is placed vertically beneath the main shaft, and the air-pump rod terminates in a block, working between vertical guides. This guide-block is driven by a short crank, by means of a connecting link, to the head of which two other links are also attached to work the remaining pumps. Upon each side of the air-pump are condensers, upon which the hot wells are placed. The air-pump bucket is furnished with a large annular valve, as shown.

The steam, having done its duty in the cylinder, passes thence into one of the condensers, whence the condensed steam and injection water are withdrawn through the clack-valves at the foot of the air-pump. On the descent of the air-pump bucket the water beneath it passes through the annular valve, and when it again ascends the water is expelled through the upper clacks into the hot wells. The throttle-valve is shown in the section of the steam-pipe above the right-hand cylinder.

The foregoing is a very fair example of one class of screw-propeller engines, and the principle is very frequently adopted, the screw-propeller of the Great Eastern being driven by engines having horizontal cylinders.

As the space is very confined in which screw engines are required to work, trunk engines are frequently used. Disc engines have also been applied, but have not come into general use. In Stothert's engines the cylinders are placed above the screw-shaft, at an angle of 45° to the horizon.

As in some cases where the air-pumps are furnished with metal valves the velocity of the engine is injuriously high, tooth-gear is applied to reduce the speed, the air-pump being driven from a secondary shaft.

# CHAPTER XXI.

## ON LOCOMOTIVE ENGINES.

The general form of locomotive engines necessarily admits of but little variation, although the details frequently present very different features. Plates XXV. and XXVI. are illustrative of a locomotive engine constructed by Messrs. Robert Stephenson and Co., for the York, Newcastle, and Berwick Railway,—the former being a longitudinal section, and the latter a horizontal section.

The engine, it will be observed, is based upon stout framing, carried upon six wheels, the centre pair acting as driving-wheels. The boiler of this engine consists as usual of two parts, the fire-box and casing, and the barrel. The fire-box is about three feet six inches wide, by three feet nine long, and five feet deep; the casing around it being four feet three inches wide, four feet six inches in length, and six feet nine in height; the fire-box and casing being stayed together by 394 ties. The fire-bars which form the grate are placed close to the bottom of the fire-box, being eighteen in number. The crown of the fire-box is strengthened by nine ribs, each of which is five inches deep at the centre and three inches at the extremities, attached to the crown of the fire-box by nine bolts. The flame and gases pass from the fire-box to the smoke-box through six rows of tubes, about one and a half inches in diameter. Above the fire-box and proceeding from the casing is the steam-whistle, also the safety-valves, and over the centre of the barrel of the boiler is the steam-dome, within which rises the steam-pipe as shown, the end of which is covered by a slide, wrought by an arm fixed upon the extremity of a shaft which passes through a stuffing-box at the back of the boiler, where a handle is attached to it to regulate the admission of the steam to the engine. A short passage from the fire-box to the casing, closed by a fire-door, affords the means of supplying the fire with

fuel. The boiler, which is well clothed, is attached to the framing by plate and angle-iron brackets. The cylinders are placed in the smoke-box; the horizontal steam-pipe from the boiler terminating in a breeches-pipe, the extremities of which communicate with the steam-chests which are placed outside the cylinders. Between the cylinders rises the blast-pipe, which terminates just below the chimney. The pistons carry piston rods, which terminate in forked-heads, through which a gudgeon passes carrying at its extremities guide-blocks, sliding between horizontal guide-bars, the extremities of these guide-bars being bolted to the brackets previously alluded to. The guide-block gudgeon is embraced by the smaller end of the connecting rod, of which the larger extremity embraces the crank-pin, both ends being furnished with suitable bearings. The cranks are forged upon the driving-axle, and outside them are bearings carried in an axle-box, placed between horn-plates, as shown, and vertically acting upon springs by which the weight of the engine and boiler is partly sustained. The driving-wheels, which have plain tires, are placed directly outside the axle-boxes, and beyond the wheels are the back and forward eccentrics, the rods of which are jointed to the extremities of a link, and as this link is raised or lowered, one or the other eccentric is caused to work the slide-valve in the manner already explained. This link is connected with one end of a double arm attached to a weigh-shaft, and to the other arm is fixed a weight to balance that of the link.

From one of the eccentrics of each pair proceeds a link by which a feed-pump placed at the side of the fire-box is worked, this feed-pump being of the ordinary plunger description, and drawing water from the tender to supply the boiler.

The leading and trailing-wheels of the engine require no special explanation, being of the ordinary description. The admission of water to the feed-pump is regulated by a stop-cock. The boiler is furnished with the usual water and pressure-gauges and gauge-cocks, and the cylinders with blow-through cocks. To the front of the framing buffers are attached, also fenders, to clear the line of obstacles.

Some locomotives are furnished with donkey-engines to supply the boiler with water while the engine is standing still. The furnaces are frequently arranged to burn coal without emitting

smoke, and the exhaust steam is sometimes caused to pass through the feed-water before being discharged from the chimney. Means are also supplied to pass the surplus steam into the feed-water when the engine is standing still.

For some time a new description of locomotive engines has been somewhat extensively employed on a northern French line of railway, and it is said with considerable success. In this engine the heated air and gases from the furnace, after traversing the tubes through the barrel of the boiler, return through other tubes on the top of the boiler, thereby superheating the steam. The funnel finally rises almost above the foot-plate. Some of these engines are furnished with four cylinders, two at each end of the framing.

# CHAPTER XXII.

## ON ROAD LOCOMOTIVES.

Coeval with Watt's great improvement in the steam-engine was the attempt to apply steam-power to propel carriages on ordinary roads, and many inventors made strenuous efforts to obtain results of practical utility; but so great were the difficulties which must be surmounted before arriving at the desired end, and so inefficient the means at disposal to overcome such obstacles, that the subject gradually ceased to absorb so much of the attention of scientific men, whose energies were turned to such branches of constructive art as appeared to promise more certain and more speedy remuneration; so that after the experiments of Murdoch, Trevethick, Gurney, Hancock, and some others, but little was heard of local locomotion until the subject was again brought before the public a few years since. The stagnation which existed for a time in this interesting department of engineering is probably due to the great interest excited on behalf of the railways; for we find, as the novelty of the latter passed off, and as railways became a part of the every-day system of life, that traction-engines, steam-carriages, and agricultural locomotives, began to reappear under more auspicious circumstances than had hitherto been attendant upon their application to practice.

The introduction, however, of steam-carriages and traction-engines into general use, was by no means so easy as it might at first sight appear, the practical difficulties being materially increased by want of experience; the mechanical facilities now at the disposal of engineers of course obviated some of the inconveniences, but it is now evident that theory, however, well considered, or however accurate in itself, is utterly useless when applied to our present subject. Experiments alone could supply

the requisite information, and as no available experience had been had, numerous experiments were found necessary, each being costly, and most of them unsatisfactory. We will now refer to the principal impediments which have from time to time arisen.

When the locomotives made their second appearance upon our roads a cry was raised by the public that horses meeting or passing them would be terrified. This objection would probably have occupied but little attention, had the public been acquainted with the real difficulties of a mechanical character; and moreover, the opinion has proved incorrect, so far as the metropolis is concerned, where the ordinary bustle of traffic was sufficient to prevent the noises of exhaust-steam and machinery in motion from attracting special attention, though there may be some danger of accidents from this cause on country roads and lanes.

The arrangement of the machinery must of course depend upon the vicissitudes to which it will be subjected, and which arise from the inequalities of the roads on which the engine is destined to work. The road will of course be liable to elevations and depressions, the effect of which will be, to raise one or both of the driving-wheels, hence the machinery will be strained. The commonest method of drawing has been as follows: The engines are fixed on the top of the boiler, and drive on to a shaft carrying spur-wheels, which act either directly or through intermediate gearing upon the driving-wheels, which were attached to the framework by springs. The result of this arrangement was, that if both driving-wheels rose, the distance between the centres of the toothed wheels was altered, and the teeth frequently broken; and, on the other hand, if one wheel alone rose through passing over an obstacle, an amount of cant would be brought upon the shafting, giving rise to a vast amount of friction, and occasionally resulting in breaking the cranks. The means of overcoming such difficulties as these do not appear very obvious, but we shall presently have occasion to refer to some engines in which even these grave obstacles are surmounted by an ingenious disposition of the machinery. Another point requiring some consideration is the means of securing sufficient adhesion between the roads and the peripheries of the driving-wheels of the engine, which, however, does not present any serious impediment to the progress of this department of mechanical engineering. We will now mention some of the principal

characteristics of the most important engines which have yet appeared.

Boydell's traction-engine was one of the first that appeared; the wheels were furnished with shoes, suspended from its periphery by iron loops, so that each shoe came down in turn upon the ground, and formed a rail over which the engine could run, the shoe being raised off the ground as soon as the wheel had left it, the series being called an endless railway, and enabling the engine to pass over soft or rocky ground with comparative ease, at the same time insuring sufficient friction to prevent the wheel from slipping.

Another traction-engine, well known, is Bray's, and the most remarkable feature about this machine is, that the wheel is furnished with movable teeth, the object of which is to give a greater hold upon soft or sloppy soil; these teeth only project to their full extent at one point of the periphery of the wheel, and at a point diametrically opposite the teeth are not visible. These teeth are attached to arms acted upon by an eccentric placed upon the axle of the driving shaft, and according to the position in which this eccentric is placed, being adjustable by a worm-wheel and tangent screw, so the teeth are caused to project at any desired part of the periphery of the driving-wheel. When running over a hard road, the teeth are not required to act, wherefore they are caused to protrude at the upper part of the wheel, whereas, if the ground be soft, they are caused to protrude at or near the bottom of the wheel. In running over soft clayey ground masses of clay adhere to the teeth, but as the latter are gradually drawn into the wheel through slots in the tire, this clay is cleaned off. There is one great disadvantage attending the use of teeth as above described, which is, that a considerable amount of power is absorbed in overcoming the friction of the teeth.

Some notable improvements were introduced into Longstaff and Pullan's traction-engines, in which the engines were carried upon vibrating frames, the gearing being always kept in its right position by means of a species of link called a sling. This engine was also heated with Pullan's superheater, whereby superior economy was obtained.

Very frequently the ordinary spur gearing described above has been dispensed with, motion being transmitted from the driving-pinion to the driving-wheel by means of a chain.

Messrs. Pullan and Lake have recently patented some improvements of a very practical and extensive character in traction-engines and road locomotives, which, indeed, appear to combine all the qualities desirable in a traction-engine. A side elevation and an end view of Messrs. Pullan and Lake's agricultural locomotive is shown at Plate XXVII. The cylinders are mounted on the top of the barrel of the boiler, as shown, the piston rod head being guided by means of a short tube, moving on a horizontal round bar. From these piston rods proceed connecting rods to a main shaft of the usual form, which is furnished with a fly-wheel, as the engine is intended to drive thrashing-machines and other agricultural machines. In the end elevation the crank-shaft and counter-shaft are omitted, their positions being indicated by the dotted lines. This engine is furnished with gearing arranged to give two speeds; the position of the gearing is shown in the drawing. Suitable clutches are furnished for working this gear. The driving-wheel is caused to rotate by means of a chain acting upon a toothed wheel, as shown. This chain is liable in the course of time to yield and become loose, wherefore it is necessary to have some means of increasing at will the distance between the counter-shaft and the axle of the driving-wheel, and such means, are supplied by the following arrangement. The axle of the driving-wheels is carried by an eccentric, which may be caused to revolve by means of a tangent screw placed beneath it, and by means of this eccentric the driving-chain can be tightened at will. The engine is furnished with a common governor, for use when it is acting as a stationary engine, and which may be disconnected when the engine is running. The reversing gear is similar to that of an ordinary locomotive, and the driving-wheels carry plates on their peripheries intended to give a better hold upon the road. These wheels may also be supplied with teeth, which may be withdrawn when necessary by means of a screw: thus we have the advantage of having movable teeth without the friction inherent to Bray's arrangement. Behind the driving-wheel and just above the eccentric, is shown in dotted lines the feed-pump, and about two feet farther, towards the hinder part of the engine, is shown an outside pump, in connection with which is a three-way cock, by means of which the pump can be used to fill the water-tank or the boiler, or to expel water through a jet, after the manner of a fire-

engine. This engine is also sometimes furnished with the super-heater above alluded to. The engine is steered by means of apparatus placed in front of the boiler, motion being imparted from a hand-wheel through suitable bevel wheels, and a pinion to the toothed segment upon the driving-axle of the leading wheels. When it would be more convenient to dispense with the steering apparatus, the latter can be removed by withdrawing it from the socke in which the bar supporting it is keyed; hence this machine may be used either as a common portable engine, drawn by horses, or as an agricultural locomotive engine.

In Pullan and Lake's traction-engine, patented at the same time as the locomotive above described, many advantages are combined. The engines are carried on a frame distinct from the boiler, and are protected from the weather by suitable covering; gearing is used for driving, in place of the chain described above, and a most beautiful and ingenious arrangement is adopted in the construction of the driving-wheels, which secures the gear against breakage. The wheels are also furnished with teeth, which may be caused to act or not by a simple adjusting contrivance, of which there are many varieties. The result of the form of this engine is such that it is quite safe in running over any ground; for, if the axis of the driving-wheels be canted in one direction and that of the leading wheels in the other, no dangerous results would ensue. Two or three of these engines have already been made, and have been found most efficient, some of them having been furnished with super heaters and some with contrivances to prevent the boiler from priming.

## CHAPTER XXIII.

### ON STEAM FIRE-ENGINES.

THE constant increase in height and other dimensions of the buildings in our large towns, has long called for more efficient means of extinguishing conflagrations than those supplied by the ordinary hand-engines. This necessity appears lately to have been better understood than before, and consequently steam fire-engines are gradually coming into extensive use.

For many years the floating fire-engines were the only ones in the metropolis worked by steam, but some time since, one of Messrs. Shand and Mason's steam fire-engines was supplied to the London Fire Brigade. This engine has a short upright boiler and a horizontal cylinder, acting direct upon the pump. Upon the piston rod is forged a slotted link, and in the slot moves a crank-pin, being part of a crank attached to a shaft, and carrying a fly-wheel and the usual gear for working the slide-valve, &c. This engine is always kept ready for service, the water in the boiler and also the steam-cylinder being kept hot by gas burners, so that in a very few minutes steam can be raised to work the engine. This engine must be looked upon in the light of an experiment which has proved eminently successful, having done good service at many metropolitan fires under the superintendence of Mr. Gerrod, the engineer to the Brigade.

Messrs. Shand and Mason have made many improvements in the engines constructed subsequently to that above mentioned, and there seems to be but little doubt of steam fire-engines coming extensively into use.

A short time since Mr. Wellington Lee, of the firm of Lee and Larned of New York, imported an American steam fire-engine,

which was tried at Mr. Hodge's distillery, under Mr. Lee's superintendence. The boiler is constructed with a view to raising steam rapidly, and in this it proved eminently successful.

An objection has been raised by some to horizontal pumps, on the ground that any grit in the water will settle upon and injure the lower part of the internal surface; but this has been contradicted, as some horizontal pumps which have been at work with foul water for some considerable time have remained uninjured. But it is certain that grit may be injurious under some circumstances, as was experimentally proved by Mr. Roberts, who caused a fire-engine to be worked with water containing a sediment, which was kept constantly stirred up while the experiment lasted, that is to say, for about twenty minutes, when it was found that the surface of the pump was much injured.

We have selected, as an example for illustration, a fire-engine of peculiar construction, manufactured by Messrs. Silsby, Mynderse, and Co., of New York. A side elevation is shown in Plate XXVIII.

It is furnished with an upright boiler of the multitubular description, containing three hundred one and a quarter inch tubes. In the lower part of the chimney is placed a fan or blower, which receives its motion from one of the hind wheels of the engine by means of a band, the object of which is to create a draught and raise the steam rapidly, while the engine is being drawn to the spot where its services are required. At the back part of the carriage and behind the boiler is fixed a rotary engine, constructed according to Holly's patent; which engine causes a shaft to rotate, the shaft passing nearly the entire length of the carriage and driving a pump constructed on the same principle as the engine, and fixed close behind the driver's seat in front of the chimney. Just below the boiler in front of the frame work, is fixed a rotary donkey engine and pump combined, similar in every respect to the main engine and pump, and intended to supply the boiler with water when the main engine is at work. An ordinary feed pump is geared by ordinary bevel wheels to the main shaft. The steam-pipe is seen proceeding from the top of the boiler in a curved form down to the rotary engine, and the exhaust-pipe is seen passing from the boiler upwards to the funnel. The usual steam-whistle,

safety-valve, and other valves and gauges are applied to the boiler; the engine is supported by india-rubber springs. A heater is furnished to heat the feed water passing to the boiler. The weight of the engine is from two to two and a half tons, and it is said to be capable of throwing a one and a half inch stream of water to a distance of a hundred and seventy feet, when working at a pressure of about fifty pounds on the square inch.

# CHAPTER XXIV.

## ON BOILERS GENERALLY, AND A RADICAL REFORM IN THOSE FOR MARINE PURPOSES SUGGESTED.

THE design of the present treatise is to place the reader in possession of sound information respecting some of the best kind of boilers at present in use, and also to indicate the course which future improvements, to be efficient and of material benefit, must necessarily pursue.

The subject of smoke-burning, which is reckoned one of the important topics of the present day, I have endeavored to illustrate in such a manner as both to correct the erroneous and exaggerated statements made by interested patentees, and to convey just and moderate ideas upon that subject.

The explosions of boilers is a question still involved in much obscurity, some of which will, I hope, be dissipated by the remarks I have offered, and as the general introduction of steam of a higher pressure seems to be inevitable, this is a subject which more than heretofore stands in need of elucidation.

I have much gratification in being able to present the present treatise enriched by the additions and corrections of MR. BOURNE, which he has kindly furnished in conformity with the friendly feeling which he has constantly manifested towards me for many years.

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## INTRODUCTORY NOTE, BY JOHN BOURNE, ESQ.

Mr. Armstrong has requested me to revise and add some notes to his present treatise on steam-boilers,—a task which my esteem for him has induced me willingly to undertake, though I do not know that any remarks of mine upon this subject can add weight to the doctrines of so established an authority. It is well known

to engineers that Mr. Armstrong has had a more extended experience, and possesses probably a more accurate practical acquaintance with boilers and furnaces than any other person now living, and the public has reason to feel grateful that an engineer of such eminent capacity upon these subjects vouchsafes to offer them the fruits of his long and extensive practice. Of all kinds of books there are none so exhausting as books upon practical engineering. Truths of the most eminent value, and results which it may have required painful labor to collect are dispatched in the compass of a few brief sentences, without any manifestation, at least to the cursory reader, of the toil and reflection involved in the brief exposition. Such works are in fact the *essence of thought.* There are consequently few of them written, and it ought to be appreciated as a service to humanity when such men as Mr. Armstrong come forward to lay before the public results which it has taken a life of labor to attain.

The three topics of which Mr. Armstrong has mainly treated in the present treatise are, first, the Necessity of Strong Boilers; second, Smoke-Burning; and third, Explosions. Upon each of these topics I propose to offer a few remarks, partly in recapitulation of what Mr. Armstrong has said, and partly as exhibiting the results of my own experience, or the nature of my own opinions on those subjects.

## HIGH-PRESSURE STEAM.

Recent investigations have led to the discovery that heat and power are mutually convertible, and we are able to tell what rise of temperature the expenditure of a given amount of mechanical power would impart to water, and reciprocally what quantity of power a given quantity of heat if used in a perfect engine would produce. One result of this discovery is the manifestation of the great loss of power in the best existing steam-engines. The best class of Cornish engines do not utilize above one-tenth part of the heat expended in working them, so that in the best engines about *nine-tenths* of the power is lost. The theoretical condition under which we would obtain the full effect of the heat in a steam-engine consists in heating the water to the temperature of the furnace, and in suffering this superheated water to expand under such cir-

cumstances, that during its expansion it would produce power. In ordinary engines, however, this condition cannot be observed, but it will be approached by using steam of a high pressure and of an elevated temperature. The economy of fuel has now become an object of paramount importance in engines of every class, but more especially so in the case of steam navigation; as there, not merely the expense of the fuel but the expense of carrying it must be incurred. To attain even a moderate measure of economy, steam of a high pressure and elevated temperature is indispensable, and if we have steam of a high pressure we must have a class of boilers introduced into steam vessels which will be able to bear it. Mr. Armstrong has addressed some of his remarks to this important question, and his opinion seems to be that a modification of that species of boiler termed sometimes the French boiler, and sometimes the Elephant boiler is the most suitable for the altered circumstances of steam navigation. It is clear that a boiler, to be able to bear a high pressure with safety, and without being encumbered with needless stays, should be a boiler with a cylindrical shell, not too large in diameter. The furnace of such a boiler may either be within it or beneath it. I cannot say that I think internal furnaces very safe with high pressures. If they get even slightly out of shape they are liable to collapse; and whereas, in the case of a cylindrical shell, the tendency of the internal pressure is to restore the cylindrical form should it have been accidentally disturbed, in the case of a cylindrical flue or furnace-tube where the pressure is external, the tendency of the pressure is to destroy the cylindrical form, should it have been disturbed accidentally, by overheating or otherwise. My opinion, therefore, is, that a fire beneath the boiler is, so far as regards safety, better than a fire within it, supposing that the water is clean and that there is no deposit. In marine boilers, however, there is a sediment like mortar, which, if allowed to subside to the bottom of the boiler, and a fire be, at the same time, applied to the bottom, will cause the iron to be burned. But by providing collecting vessels within the boiler the deposit will take place within them, and may be from thence blown out into the sea; and if the operation of blowing off the boilers be sufficiently practised, there will, in point of fact, be no sediment at all. By the application, therefore, of such simple expedients as a collecting vessel and a continuous blow-off,

boilers may be employed for marine purposes which will not accumulate scale; and, if the formation of scale be prevented, a species of boiler may be used which will enable high-pressure steam to be employed with safety. Steam of this kind, used expansively in the engine, will maintain any required speed of the vessel with a much smaller consumption of coal than would otherwise be required.

In all engines working expansively it is important to maintain the temperature of the cylinder as high as possible, since the temperature of the steam is diminished, and a portion of it is even condensed within the cylinder in consequence of the communication of mechanical power to the piston. For, as a certain weight of steam has a certain mechanical equivalent which would be realized if the steam could be used in an engine without waste, it follows that the steam, in so far as it exerts power, must lose heat, else it would have both the power and the heat, which is impossible. Accordingly, it is found that there is a larger condensation in the cylinder of an engine which is at work than would take place if the engine were not at work, although the steam is admitted to the cylinder freely in both cases. When the engine is stationary the whole condensation is that caused by the radiation of heat: when the engine is at work we have, besides this cause, the communication of mechanical power to the piston, which can only be effected at the expense of some of the heat, and therefore, with a certain condensation of the steam within the cylinder. In a perfect engine there would be no heat discoverable in the condenser, as the whole would have been changed into mechanical power; and, in all engines, there will be an inferior quantity of heat in the condenser to that which leaves the boiler, by the equivalent in heat of the mechanical power generated in the engine. Steam-jackets act in counteracting the condensation caused by the communication of power.

## SMOKE-BURNING.

With respect to smoke-burning, the best species of furnace for the accomplishment of this object, without the introduction of countervailing evils, is one which Mr. Armstrong has designed for Woolwich Dock Yard, on a nearly similar plan to several erected

by him in the Arsenal. In this furnace the foremost length of bars slopes somewhat towards the mouth; whereas, the after lengths of bars slope in the contrary direction, or towards the bridge. At the ridge where the opposite slopes meet, there is a double bearing bar which permits some air to enter the furnace in that situation. The coal in the foremost length of bars is maintained in rapid combustion, whereas the coal upon the after tier of bars is undergoing a slow distillation. In charging the furnace, the coal is thrown chiefly to the back end, so that the surface of the fuel slopes forward from the bridge towards the furnace mouth. This coal, being lighted on the top, becomes a kind of coal torch. The gas generated by the heat, in passing through the ignited stratum on the surface, is consumed; and, from time to time, the ignited embers, from which the gas has been expelled, are raked forward, and fresh coal is thrown in to maintain the combustion. Very little smoke is evolved from this species of furnace; and it differs little from a common furnace, either in construction or efficiency.*

The best species of furnace, however, for marine purposes, is one which, while fulfilling all other indications, will feed the fire by self-acting mechanism. The firing may be accomplished by some of these expedients, not merely in a more efficient manner, but at a materially diminished expense. In the case of a boiler on land, in which a man to look after the engine and boiler is required in any case, the introduction of a firing machine to do a portion of his work is not an object of much importance. But in the case of the furnaces of a steam-vessel, which require a number of men to attend upon them every watch, an important economy would be accomplished by the substitution of mechanism of an efficient character.

## EXPLOSIONS.

The subject of boiler explosions is still involved in a good deal of obscurity. No doubt a frequent, and probably the most frequent, cause of explosion, is the sudden generation of steam produced when the water-level has been allowed to fall so low that

* A representation of this newly designed furnace, as applicable to an "Elephant" Boiler, suitable for dockyards, saw-mills, &c., where waste timber and other varieties of mixed fuel are used, is given in the frontispiece.

the flues get very hot, and then is suddenly raised, so that the water comes into sudden contact with the heated metal. But there are other cases, in which the water is repelled from the iron by a strong heat, though no undue subsidence of the water-level has been suffered to take place. There are boilers in which the natural order of things is reversed when heat is applied,—the water being mostly in the top part of the boiler, and the steam in the bottom. Such boilers necessarily prime very much; or, in other words, much water passes into the steam-pipe, and, at the same time, the part of the boiler on which the flame acts is liable to become overheated from the absence of water in contact with the metal to conduct away the heat. There are boilers in which a lead rivet in the flues may, at any time, be melted out by firing very strongly; the water being so far repelled by the heat as to enable the temperature of the metal to rise to the melting point of lead.

In all boilers in which there is ebullition going on, the apparent level of the water will be greater than the true level, as the admixture of steam swells the water, producing what is call "false water," by the drivers of locomotives. One effect of this fictitious augmentation of bulk is, that when additional feed water is turned on, from the water-level becoming too low, the first effect is still further to lower the water-level. This anomaly is caused by the condensation of the steam mixed with the water of the boiler, when an additional quantity of cold or cool water is introduced; but the water level may, at such times, be again raised by easing the safety-valve, which will enable the steam mixed with the water to swell to larger dimensions when the pressure is reduced, and thus compensate for the partial condensation which the introduction of additional feed water has caused.

One cause of boiler explosions Mr. Armstrong considers to be the unskillful application of smoke-burning projects, which by producing violent alternations of temperature in the boiler bottom, loosen the riveted joints, and, finally cause them to give way. The occurrence of an accident of this kind in a boiler fitted with the smoke-burning furnace of Mr. Charles Wye Williams has led to a wordy war, which has been waged by that lively gentleman for many years. Mr. Williams is a species of amateur engineer; who, on the strength of an acquaintance with the atomic theory,

and other elementary chemical truths, acquired, apparently, late in life, has set up as the engineering reformer of the age, in the department of smoke-burning; and he has obtained the approbation of the "Mechanic's Magazine" and other oracles of corresponding authority. A man's ambition need not be very exalted, which is satisfied with such successes; but if there be gratification sufficient to compensate the ridicule arising from harping eternally upon a single trumpery topic, there is no reason, that I know of, why it should not be possessed.

The subject of locomotive boilers has been treated more fully by Mr. D. K. Clark, in his excellent work on "Railway Machinery," than by any other author, and he has shown that it is inadvisable to make the area of fire-grate or the area of the chimney very large, that the smoke-box should not be of greater capacity than is absolutely necessary to collect the hot air from the tubes, and that the blast-pipe should stop short, by a few inches, of the foot of the chimney, instead of penetrating into it. The following table is taken from Mr. Clark's work:—

TABLE OF THE PROPERTIES OF SATURATED STEAM FROM REGNAULT'S EXPERIMENTS.

| Total pressure per square inch. | Relative volume. | Temperature. | Total Heat. | Weight of one cubic foot. |
|---|---|---|---|---|
| lbs. | | Fahr. | Fahr. | lbs. |
| 15 | 1669 | 213·1 | 1178·9 | ·0373 |
| 16 | 1572 | 216·3 | 1179·9 | ·0397 |
| 17 | 1487 | 219·5 | 1180·9 | ·0419 |
| 18 | 1410 | 222·5 | 1181·8 | ·0442 |
| 19 | 1342 | 225·4 | 1182·7 | ·0465 |
| 20 | 1280 | 228·0 | 1183·5 | ·0487 |
| 21 | 1224 | 230·6 | 1184·3 | ·0510 |
| 22 | 1172 | 233·1 | 1185·0 | ·0532 |
| 23 | 1125 | 235·5 | 1185·7 | ·0554 |
| 24 | 1082 | 237·9 | 1186·5 | ·0576 |
| 25 | 1042 | 240·2 | 1187·2 | ·0598 |
| 26 | 1005 | 242·3 | 1187·9 | ·0620 |
| 27 | 971 | 244·4 | 1188·5 | ·0642 |
| 28 | 939 | 246·4 | 1189·1 | ·0664 |
| 29 | 909 | 248·4 | 1189·7 | ·0686 |

| Total pressure per square inch. | Relative volume. | Temperature. | Total Heat. | Weight of one cubic foot. |
|---|---|---|---|---|
| lbs. | | Fahr. | Fahr. | lbs. |
| 30 | 881 | 250·4 | 1190·3 | ·0707 |
| 31 | 855 | 252·2 | 1190·8 | ·0729 |
| 32 | 830 | 254·1 | 1191·4 | ·0751 |
| 33 | 807 | 255·9 | 1192·0 | ·0772 |
| 34 | 785 | 257·6 | 1192·5 | ·0794 |
| 35 | 765 | 259·3 | 1193·0 | ·0815 |
| 36 | 745 | 260·9 | 1193·5 | ·0837 |
| 37 | 727 | 262·6 | 1194·0 | ·0858 |
| 38 | 709 | 264·2 | 1194·5 | ·0879 |
| 39 | 693 | 265·8 | 1195·0 | ·0900 |
| 40 | 677 | 267·3 | 1195·4 | ·0921 |
| 41 | 661 | 268·7 | 1195·9 | ·0942 |
| 42 | 647 | 270·2 | 1196·3 | ·0963 |
| 43 | 634 | 271·6 | 1196·8 | ·0983 |
| 44 | 621 | 273·0 | 1197·2 | ·1004 |
| 45 | 608 | 274·4 | 1197·6 | ·1025 |
| 46 | 595 | 275·8 | 1198·0 | ·1046 |
| 47 | 584 | 277·1 | 1198·4 | ·1067 |
| 48 | 573 | 278·4 | 1198·8 | ·1087 |
| 49 | 562 | 279·7 | 1199·2 | ·1108 |
| 50 | 552 | 281·0 | 1199·6 | ·1129 |
| 51 | 542 | 282·3 | 1200·0 | ·1150 |
| 52 | 532 | 283·5 | 1200·4 | ·1171 |
| 53 | 523 | 284·7 | 1200·8 | ·1192 |
| 54 | 514 | 285·9 | 1201·1 | ·1212 |
| 55 | 506 | 287·1 | 1201·5 | ·1232 |
| 56 | 498 | 288·2 | 1201·8 | ·1252 |
| 57 | 490 | 289·3 | 1202·2 | ·1272 |
| 58 | 482 | 290·4 | 1202·5 | ·1292 |
| 59 | 474 | 291·6 | 1202·9 | ·1314 |
| 60 | 467 | 292·7 | 1203·2 | ·1335 |
| 61 | 460 | 293·8 | 1203·6 | ·1356 |
| 62 | 453 | 294·8 | 1203·9 | ·1376 |
| 63 | 447 | 295·9 | 1204·2 | ·1396 |
| 64 | 440 | 296·9 | 1204·5 | ·1416 |
| 65 | 434 | 298·0 | 1204·8 | ·1436 |
| 66 | 428 | 299·0 | 1205·1 | ·1456 |
| 67 | 422 | 300·0 | 1205·4 | ·1477 |
| 68 | 417 | 300·9 | 1205·7 | ·1497 |
| 69 | 411 | 301·9 | 1206·0 | ·1516 |
| 70 | 406 | 302·9 | 1206·3 | ·1535 |
| 71 | 401 | 303·9 | 1206·6 | ·1555 |

| Total pressure per square inch. | Relative volume. | Temperature. | Total Heat. | Weight of one cubic foot. |
|---|---|---|---|---|
| lbs. | | Fahr. | Fahr. | lbs. |
| 72 | 396 | 304·8 | 1206·9 | ·1574 |
| 73 | 391 | 305·7 | 1207·2 | ·1595 |
| 74 | 386 | 306·6 | 1207·5 | ·1616 |
| 75 | 381 | 307·5 | 1207·8 | ·1636 |
| 76 | 377 | 308·4 | 1208·0 | ·1656 |
| 77 | 372 | 309·3 | 1208·3 | ·1675 |
| 78 | 368 | 310·2 | 1208·6 | ·1696 |
| 79 | 364 | 311·1 | 1208·9 | ·1716 |
| 80 | 359 | 312·0 | 1209·1 | ·1736 |
| 81 | 355 | 312·8 | 1209·4 | ·1756 |
| 82 | 351 | 313·6 | 1209·7 | ·1776 |
| 83 | 348 | 314·5 | 1209·9 | ·1795 |
| 84 | 344 | 315·3 | 1210·1 | ·1814 |
| 85 | 340 | 316·1 | 1210·4 | ·1833 |
| 86 | 337 | 316·9 | 1210·7 | ·1852 |
| 87 | 333 | 317·8 | 1210·9 | ·1871 |
| 88 | 330 | 318·6 | 1211·1 | ·1891 |
| 89 | 326 | 319·4 | 1211·4 | ·1910 |
| 90 | 323 | 320·2 | 1211·6 | ·1929 |
| 91 | 320 | 321·0 | 1211·8 | ·1950 |
| 92 | 317 | 321·7 | 1212·0 | ·1970 |
| 93 | 313 | 322·5 | 1212·3 | ·1990 |
| 94 | 310 | 323·3 | 1212·5 | ·2010 |
| 95 | 307 | 324·1 | 1212·8 | ·2030 |
| 96 | 305 | 324·8 | 1213·0 | ·2050 |
| 97 | 302 | 325·6 | 1213·3 | ·2070 |
| 98 | 299 | 326·3 | 1213·5 | ·2089 |
| 99 | 296 | 327·1 | 1213·7 | ·2108 |
| 100 | 293 | 327·8 | 1213·9 | ·2127 |
| 101 | 290 | 328·5 | 1214·2 | ·2149 |
| 102 | 288 | 329·1 | 1214·4 | ·2167 |
| 103 | 285 | 329·9 | 1214·6 | ·2184 |
| 104 | 283 | 330·6 | 1214·8 | ·2201 |
| 105 | 281 | 331·3 | 1215·0 | ·2218 |
| 106 | 278 | 331·9 | 1215·2 | ·2230 |
| 107 | 276 | 332·6 | 1215·4 | ·2258 |
| 108 | 273 | 333·3 | 1215·6 | ·2278 |
| 109 | 271 | 334·0 | 1215·8 | ·2298 |
| 110 | 269 | 334·6 | 1216·0 | ·2317 |
| 111 | 267 | 335·3 | 1216·2 | ·2334 |
| 112 | 265 | 336·0 | 1216·4 | ·2351 |
| 113 | 263 | 336·7 | 1216·6 | ·2370 |

| Total pressure per square inch. | Relative volume. | Temperature. | Total Heat. | Weight of one cubic foot. |
|---|---|---|---|---|
| lbs. | | Fahr. | Fahr. | lbs. |
| 114 | 261 | 337·4 | 1216·8 | ·2388 |
| 115 | 259 | 338·0 | 1217·0 | ·2406 |
| 116 | 257 | 338·6 | 1217·2 | ·2426 |
| 117 | 255 | 339·3 | 1217·4 | ·2446 |
| 118 | 253 | 339·9 | 1217·6 | ·2465 |
| 119 | 251 | 340·5 | 1217·8 | ·2484 |
| 120 | 249 | 341·1 | 1218·0 | ·2503 |
| 121 | 247 | 341·8 | 1218·2 | ·2524 |
| 122 | 245 | 342·4 | 1218·4 | ·2545 |
| 123 | 243 | 343·0 | 1218·6 | ·2566 |
| 124 | 241 | 343·6 | 1218·7 | ·2587 |
| 125 | 239 | 344·2 | 1218·9 | ·2608 |
| 126 | 238 | 344·8 | 1219·1 | ·2626 |
| 127 | 236 | 345·4 | 1219·3 | ·2644 |
| 128 | 234 | 346·0 | 1219·4 | ·2662 |
| 129 | 232 | 346·6 | 1219·6 | ·2680 |
| 130 | 231 | 347·2 | 1219·8 | ·2698 |
| 132 | 228 | 348·3 | 1220·2 | ·2735 |
| 134 | 225 | 349·5 | 1220·6 | ·2771 |
| 136 | 222 | 350·6 | 1220·9 | ·2807 |
| 138 | 219 | 351·8 | 1221·2 | ·2846 |
| 140 | 216 | 352·9 | 1221·5 | ·2885 |
| 142 | 213 | 354·0 | 1221·9 | ·2922 |
| 144 | 210 | 355·0 | 1222·2 | ·2959 |
| 146 | 208 | 356·1 | 1222·5 | ·2996 |
| 148 | 205 | 357·2 | 1222·9 | ·3033 |
| 150 | 203 | 358·3 | 1223·2 | ·3070 |
| 160 | 191 | 363·4 | 1224·8 | ·3268 |
| 170 | 181 | 368·2 | 1225·1 | ·3443 |
| 180 | 172 | 372·9 | 1227·7 | ·3623 |
| 190 | 164 | 377·5 | 1229·1 | ·3800 |
| 200 | 157 | 381·7 | 1230·3 | ·3970 |

NOTE. The above table of corresponding pressures, temperatures, and volumes of saturated steam is by the kind permission of Mr. Clark copied from his valuable work. The pressures and temperatures are the direct results of M. Regnault's experiments. The relative volumes are obtained by means of the formula

$$v = 37{\cdot}3\,\frac{458 + t}{p}.$$

The fourth column is the result of direct experiment by Regnault. And the fifth column is calculated by dividing 62·321 lb., the weight of a cubic foot of water at 62° by the relative volume.

With these cursory remarks I dismiss Mr. Armstrong's present work. Its main suggestions, namely, the necessity of the adoption of cylindrical boilers in all cases in which economy of fuel is important, the practicability of burning smoke by simple arrangements without, however, the accomplishment of much, if any direct saving of fuel, the advantage of fire-feeding mechanisms in steam-vessels, and the doctrine of the accidental deficiency of water in boilers being the main cause of explosions, are all, in my judgment, sound doctrines, and, if so, public benefit cannot fail to arise from their wide acceptation.

J. B.

## ON BOILERS GENERALLY.

The main design of this short essay is to impart in few words, that information respecting boilers and furnaces, which persons employing steam-engines desire to possess, but which they have not much time to acquire. While yielding our approbation to all investigations touching the science of steam which seem likely to illustrate its nature, we are at the same time conscious that the bulk of mankind immersed in active business have but little time for such speculations; and it is our design rather to state results, and enunciate general laws, such as are found to govern successful practice, than to embark upon the wide sea of theoretical disquisition, or to announce any mere theoretical conclusions. Still less is it our intention to parade the elementary truths of chemistry as baits for the admiration of the ignorant—expanded into all the forms proper to laborious dulness and varied in every phrase of emphatic iteration. *That* task has already been performed by Mr. Charles Wye Williams in his work on the "Combustion of Coal and the Prevention of Smoke," and the merits in which that work is deficient have been compensated by its artificial notoriety. We should be sorry to deprive Mr. Williams of any portion of the reputation which has cost him so much and the quality of which seems to satisfy his ambition, and there is certainly no danger that in the present work we shall run into any similar extravagance, having so painful an example before us of this species of folly. To theory we take no exception, theory being indeed only the connection of individual facts into such a chain as to constitute a natural law.

## HAY-STACK BOILER.

This boiler is termed the hay-stack boiler from its shape. In some districts it is called the *balloon boiler*, and the *kettle boiler.* It is a good kind of boiler up to 10 or 12-horse power, and 10 or 12 lbs. pressure, where boilers are required to stand singly. It is strong enough within those limits, and has the greatest capacity for the least quantity of material employed. Independent of its economy, which, with inferior fuel, need not be less than that of any other kind, it has, perhaps, the greatest evaporating power for its dimensions, and if set up, as it usually is, with a single wheel draft, it requires only a small chimney. The shape of the bottom of this boiler is generally not so well adapted as some other kinds of boilers for applying the usual arrangements for consuming smoke, but if made of copper, as such boilers are in some of the London breweries, they admit of coke being used to very great advantage.

In Staffordshire, and some other mining-districts, the hay-stack boiler has been frequently made much too large; and where this defect has been sought to be corrected, by carrying the flue spirally twice round the boiler, the result has usually been unsuccessful, if not dangerous.

## THE WAGON BOILER.

This boiler is, in principle, the hay-stack boiler just described, only put into an *oblong* instead of a circular form on the ground plan. It therefore permits of facilities in arranging a number of boilers side by side without wasting space. It is distinguished in mining-districts as the *oblong* boiler. In other places it is sometimes called the *caravan* boiler, and by Mr. Wicksteed, the *wagon-head* boiler. It possesses some advantage over the hay-stack boiler in its being better adapted for the use of rich bituminous or flaming fuel, and Newcastle coal generally. It admits of being made of such a length, that the flame from the well-managed fire will be generally expended before reaching the end; and it can be easily varied in its proportions to suit the many varieties of flaming fuel,—wood as well as coal. As flaming coal is also *smoky* coal,

the wagon boiler from its rectangular plan is suitable for the application of such coal, because it admits of the ordinary rectangular fire-grate, with convenient space beyond for any arrangement of the furnace chamber and bridges, so as to meet almost any requirement for smoke-consuming purposes.

The wagon boiler is, except in the direction of its length, nearly as strong as the hay-stack boiler, up to five feet diameter, and if provided with one, two, or three longitudinal stays, and four such stays of one and a half inch square from end to end if above that diameter, together with cross-stays at every two feet in the length, it may be safely worked up to ten pounds on the square inch. For this pressure it is usually made of plates to average three-eighths of an inch thick all round, the top being never less than one-quarter, and the ends ought to be seven-sixteenths of an inch. Up to 20 or 25 horse-power, boilers which are as many feet in length by five to five and a half feet wide, or equivalent proportions, made in this way, will weigh seventeen or eighteen pounds per square foot of total surface, inclusive of rivets, overlap of plates, stays, &c. Seventeen or eighteen square feet of such surface may be reckoned as equivalent to a horse-power; from these data, the weight and cost (at present twenty-five to thirty shillings per hundred weight) is soon obtained.

Within the above limits, no boiler ever made can exceed this one in efficiency, economy, and durability, if well-proportioned to the engine it works, and to the fuel supplied to it. If required of greater power than 20 or 25 horse, boilers of this kind are made deeper in proportion to their length, and an internal *flue tube* is introduced, and such boilers are then called the

### BOULTON-AND-WATT BOILER.

This boiler, when of 30 or 40 horse-power, is more economical in fuel than the plain wagon form; but is weaker for the same thickness of iron, and ought not to be worked at more than eight pounds per square inch. Its power is calculated in the same way as that of the wagon boiler, excepting only that the breadth or diameter of the internal tube is to be considered as so much added to the width of the boiler itself. Thus, if a wagon boiler of twenty feet long, by five feet wide, be equal to 20 horse-power, being at the

usual rate of five square feet of water surface or horizontal ground plan per horse-power,—then a Boulton-and-Watt boiler of the same horizontal dimensions externally, but having its inside flue tube of two feet diameter, will be *two-fifths* more powerful, or 28 instead of 20 horse-power; it must be supplied, of course, with a proportionate increase of fire-grate, and is thus computed:—

$$\frac{\text{Length } 20\text{ ft.} \times (5+2=)\ 7\text{ ft. wide}}{\text{Divided by } 5\text{ feet per H. P.}} = \frac{140}{5} = 28$$

horse-power.

With these dimensions, however, it would have to be of very considerable depth, in order to have the required capacity for holding a sufficient quantity of water and steam for that power. It is therefore found preferable to make such boilers from six to eight feet wide, by eight or nine feet deep, and they should never be more than twenty-eight or thirty feet long. If a boiler of this kind is not required to be above 40 horse-power, there is no necessity, unless very bituminous coal is used, for its being much more than twenty feet in length. With that length it may be made 6 ft. 6″ wide, by 8 ft. or 8 ft. 6″ deep, and contain a circular flue-tube of three and a half feet in diameter. The computation in the same manner as above, will then stand as follows:—

$$\frac{20\text{ ft.} \times (6\text{ ft. } 6'' + 3\text{ ft. } 6'' =)\ 10\text{ ft.}}{5} = \frac{200}{5} = 40\text{ H. P.}$$

As in my former works upon steam-boilers, I gave some examples of the arithmetical calculations connected with this subject, at full length, for the special benefit of engine-men and stokers, and having since ascertained the utility of such numerical examples for the purpose intended, I shall give a similar example here:—

| | | |
|---|---|---|
| Width or diam. of boiler, | | 6·5 feet. |
| Ditto of inside flue-tube, | | 3·5 |
| | | 10·0 |
| Multiply by the length | | 20 |
| Divide by . . . . | 5 | 200 |
| | | 40 horse-power. |

The slide-rule formula for all such cases is,

| A | Gauge-point 5 | or 5·7 | diam. of boiler and flue 10 |
|---|---|---|---|
| D | Horse-power 40 | 35 | Length of ditto 20 |

If the second divisor or gauge-point 5·7 be used, which gives about a square yard, or nine square feet of effective heating surface per horse-power, the result is seen to be only 35 horse-power. But, by placing 40, the power required, opposite to 5·7 in the place of 35, we shall find, opposite to 10, the proper length to make the boiler 40 horse-power at that rate, namely, 22·8 feet, as below,

| A | 5·7 | diameter 10 | or 11½ |
|---|---|---|---|
| D | 40 | length 22·8 | 20 |

or, retaining the same length twenty feet as before, opposite to it is seen eleven and a half, as above, for the diameters of boiler and flue together, which may be conveniently made eight feet, and three feet six inches respectively.

A Boulton-and-Watt boiler, thus proportioned, is much more economical of fuel than a wagon boiler of the same size or power; but it requires more total surface of iron-plate, although it is measured precisely in the same way, that is, the *lower half* of all the flues is left out in the measurement, as non-effective in generating steam, and one-half only of the vertical heating-surface is considered as *effective* heating-surface.

In respect to strength, this boiler is weaker than the unflued wagon form, in proportion as its depth exceeds its diameter,—notwithstanding it may be made of thicker plates in proportion to its increased size. This defect is partially remedied by having *two* tiers of cross-stays 1¼″ square, placed one above and the other below the inside flue. Besides these cross-stays, it is usual to support the bottom of the boiler by oblique stays, commonly called "upright" stays, attached to the arch of the boiler-bottom, and the other end secured by cotters upon and near the ends of the upper cross-stays. All these stays, of which there are four for each plate in the length of the boiler, are attached by broad wrought-iron straps and cotters, which last should not be made too taper, for when so they are liable to wriggle loose by the working of the boiler. Besides the usual number of longitudinal stays from end to end, as in the plain wagon boiler, some persons put in "angle stays," extending from near the centre of each end to the second or third plate on each side. Again, we occasionally find a stay

carried obliquely downwards from the flat end of the boiler to the top of the flue-tube, which we consider injudicious, and rather tending to do harm than good. For the tube itself generally is or should act as a stay from end to end; and on that account should not be drawn out of its direct tensile action by any side-attachment, liable to create lateral strain. The probable reason why stays were originally placed in this part by Boulton, Watt and Co. is, that they did not latterly carry the flue-tube right through from end to end, but terminated in a *flat* topped "take-up" inside the boiler, to support the top plate of which this oblique stay assisted. With respect to similar oblique or angular stays carried from the ends to the *arched top* of the boiler, we cannot say much in their favor, although some of them have become popular under the name of "*gusset*" stays, from their being made of triangular plates instead of square bars, which would, we think, be more suitable, if needed at all. However appropriate these gusset stays, or stay *plates*, instead of stay *bars*, may be in plate-iron bridges and structures of that kind, where stiffness from external pressure and from twisting is the main object in view, any peculiar value they can have in resisting the internal strains to which steam-boilers are subject, is not very apparent, especially when we consider that every unnecessary rivet, not to say seam of rivets, in a boiler is a source of weakness, not strength.

If larger boiler-plates could be manufactured, or could large plates be as easily ascertained to be sound as small ones, then the less rivetting the better. Since the new system of welding instead of rivetting the edges of boiler-plates together has been so far perfected by the patent process of Mr. Bertram, late of Woolwich Dockyard, as to prove its superior strength to even double-rivetting, it is not now too much to look forward to the time when not only a boiler, but the iron hull of "the noblest machine that ever was invented," a SHIP, instead of being, as it may now be termed, "*stitched*" together in patches by "seams" and "gussets," will be *forged* in one entire piece. At all events, Mr. Bertram has demonstrated the practicability of welding together iron plates in a cheap, rapid, and efficient manner, and there can be no doubt that his discovery must in time find many valuable applications.

## MARINE BOILERS.

In this country marine boilers are almost all low-pressure boilers but the pressure has been gradually creeping up for several years, and pressures of from 20 to 30 lbs. on the square inch are now by no means unusual. At the same time no corresponding improvements have been made in the structure of the boilers, to insure an equal measure of safety to that which previously existed. No doubt modern marine boilers are made of good iron, are well riveted, and are very much stayed. But the stays, especially in the region of the steam-chest, are speedily corroded by the action of the steam. The plates of the boiler also get thin, so that unless the engineer reduces the weights on the safety-valve as the boiler gets worn, explosion will be apt to occur from mere weakness of the boiler.

For tug-boats and other commercial purposes, for war, and for sea-going vessels generally, we do not see how very high pressure, whether with condensing or non-condensing engines, and for war ships, *extreme* high pressure is to be avoided. The economy of the combined high and low-pressure engine, and the advantages of working very expansively, in various ways are so great, and so much more important *afloat*, where the fuel has to be *carried*, than ashore, that it has long been a problem whether it would not eventually be true economy to adopt the very strongest boilers which can possibly be made at once,—say to be able to work at not less than 100, and up to 200 lb. on the square inch,—and we really see no very great difficulty in making boilers quite as safe from explosion at 200 lb. as the ordinary marine boilers as now made are at 20 lb. pressure. It is merely a question of investment of capital, not in *large* ships, but in *strong* ships, so that we are inclined to side with those who would adopt such a system as good commercial policy. Because if the boilers are capable of working safely at 200 lbs., there is no reason why, with proper arrangements, such boilers, with suitable engines, should be less economical than ordinary boilers if worked at ordinary pressures. The greater cost of the boiler in the first instance will not only confer greater strength, but greater durability.

The present construction of the *multitubular* boiler, as it is called, may be truly stated as a disgrace to the science of this age

of progress. The marine boiler yet remains, in fact, no more than a locomotive boiler, with the most important part of that boiler, the fire-box, left out. It is not that we would put a fire-box, or any thing like it, aboard a steam-ship, though well adapted to the rail. That is only suited for burning coke, which is too bulky a fuel for marine purposes. Besides, a blast, or strong draft, by some means, seems a necessity for burning coke with advantage.

Very much more, however, is either the blast or jet required, by reason of the multitude of small tubes through which the products of the combustion must be drawn. This creates an additional difficulty with the present marine boiler, and it is not likely that from twenty to thirty per cent. of its power can be afforded for blowing the fire, as is the case with some locomotives.

What, then, it may be asked, is the first step to improve the present practice? And my answer is ready: If a *moderate* improvement only is permitted, without greatly disturbing present arrangements of space in the ship, and a due regard to venerated prejudices, which we have seen created during a single generation, and which have in that time erected the crude suggestion of Booth, successful though it has been made by others, almost into the position of an institution, the obvious course is to *improve the furnaces, shorten and widen the tubes*, and, when draft is deficient, *apply the exhausting fan* with a short funnel. Although we do not insist so strongly on the last item, it may be observed, in passing, that it would make "smoke-burning" *with economy* in steamships possible. At present it is not. (*See* Chap. xxv.)

Should a radical reform of the marine boiler be aimed at,—and we have never ceased strenuously to urge its necessity,—whoever attempts it must not stick at trifles. The boilers, in the first place, ought not to be "crushed down" to the bottom of the ship, where the draft has such difficulty to descend down after them. We would, in fact, abolish the stoke-*hole*, if not do away with the stokers, and *stoking* also. Instead of placing the fires so low down that, in a leaky ship, they are soon drowned out, we would have them close up to the deck, in whatever situation the engines might be fixed. The "firing-stage" should really be a platform elevated to the light of day, on which the most important processes in the economy and progress of a steam-vessel is carried on, and to which the coals may be elevated, and, if required, placed in the furnaces

also, by means of very simple self-acting mechanical appliances. In giving a reluctant assent to the proposition, let it not be forgotten by the reader that this change of position in the boilers would really *increase* the available room for cargo, inasmuch as none would be wasted in passages up and down for the hands, and for ventilation,—to say nothing of the greater safety of the ship from *fire;* and though last, not least, when we think of the possible fate of the "President" or the "Pacific," from *explosion.*

In the case of vessels of war where the boilers, in this elevated position, might be obnoxious to the effects of shot, &c., the boilers may be retained in the usual position, and in such cases the room occupied by the stoking-space is not so objectionable. Wrought-iron boilers of simple forms, containing a steam-pressure of 200 lbs. per square inch, will be the most suitable in such cases.

The communication of the boilers with each other and with the cylinders may be easily arranged below the water-level in the manner of the locomotive.

The kind of boilers we propose for marine purposes are not new schemes, but the inventions of practical men, matured by the experience afforded by extensive use. The principle is that of WOOLF where the pressure is exerted only *within* cylinders of comparatively small diameter, say up to two and a half or even three feet. The species of boiler made by Hall of Dartford, and others, known in London as the *elephant* boiler, may be arranged to work at a pressure of 150 to 200 lbs., and for low-pressure (say 80 to 100 lbs.) when used in wooden vessels where *internal* furnaces are insisted on, we would recommend the modification patented by Galloway, of Manchester. The elephant boiler has been much used by the French, though but partially, perhaps, for steam-navigation. Galloway's boiler has been used in this capacity, I believe, to some extent; my own immediate experience with both has been principally confined to *land.* The latter boiler was first introduced into practice in London, and erected for public inspection and trial at the Great Exhibition in 1851. This boiler I shall now describe.

## THE GALLOWAY CONICAL-TUBE BOILER.

I use the term "conical," rather than "patent," in the designation of this boiler, because the patentees have other patent boilers also.

with vertical tubes, which tubes are not all conical, being partly "fire-tubes," or, strictly speaking, small tubular flues, on the principle of the locomotive; and also to distinguish it in its most prominent feature, in relation to strength and durability, from the boilers of the American steamers "Pacific" and "Baltic," Collins's line. The great and most important point of difference between the American and English boiler is, that in the former, the large internal fire-flue, or flame-chamber is occupied by a great number of *parallel* tubes, about two inches diameter, and five feet long, placed vertically, and connecting the upper and lower portions of the water-chamber. Through these tubes the water, of course, circulates very rapidly, and there can be no doubt this arrangement forms a most effectual means of warming a large quantity of water in a short time, and with great economy. Whereas in the Galloway boiler, the space behind the furnace is occupied by a smaller number of *taper*, or conical tubes of five or six inches in diameter at the lower, and nearly double that diameter at their upper ends; consequently requiring more space in length of boiler, though less in depth, than the American plan, for the same quantity of heating-surface.

In a pamphlet written by Captain Ramsay, R.N., published in 1851, entitled, "Remarks on some of the causes that retard the progress of our STEAM-NAVY," several good observations are made in illustration of the necessity of using much higher steam than previously, in ships of war, and the difficulty in attaining that object with the ordinary construction of marine boiler, as well as on the ill-adaptation of that boiler with small tubes to the proper combustion of bituminous coal or other flaming fuel. In discussing this subject, page 58, Captain Ramsay remarks:—

"The strongest form of boiler which we are acquainted with is one invented by Messrs. J. and W. Galloway, of Manchester, and which, we believe, might, with modifications, be adapted to marine purposes. The peculiar principle of this boiler is the series of short vertical tubes which act as stays. The only objection to which these boilers are liable, as marine boilers, would be, that using *water*-tubes, there is a liability to prime; but we would meet that objection by making the upper part of the tubes very large in proportion to the lower parts."

Now, this last suggestion is a very important one, and had been

previously made by the present writer, not with a view to prevent priming, solely, but also for insuring a more effective action of the flame against the sides of the tubes, as well as to prevent their being injured by overheating and burning out at their upper ends. In fact, I professionally advised the inventors, on being consulted by them, previously to taking out their patent for this water-tube boiler, in 1850, to adopt that course. This advice they followed, and have continued to pursue, with very great success ever since. Messrs. Galloway having supplied several fifty horse boilers, for the Gutta Percha Company's Works, City Road, and to several other factories in London, during that and the following year.

One of those boilers, erected under my superintendence at the City Road Works, is described and figured in my "Rudimentary Treatise on Steam-Boilers." In that work it was stated that this boiler was capable of evaporating a cubic foot of water per minute, with only about six lbs. of bituminous coal per hour, not of the best quality, while driving a thirty-horse non-condensing engine indicating fifty horse power, besides supplying steam for other purposes. This great, if not unprecedented, degree of economy has been doubted by some persons who have in vain tried to evaporate a cubic foot of water by less than eight or nine lbs. under the same circumstances: that is, *while driving an engine at full work*, which is a very different thing to the kind of evaporating-experiments some time ago carried on by order of Government, and published in sundry Reports to Parliament on coals suited to the steam-navy. These Reports are merely an account of the results of certain laboratory experiments, and, however valuable as scientific facts such investigations may be, it must be said that the labors of the eminent men engaged have been of little use in improving or illustrating the actual practice of engineers. The highest result obtained in these experiments was 10·21 lbs. of water evaported from 212° for each lb. of the best Welsh coal. (Ebbw Vale.) This result was obtained with a Cornish boiler. With a Galloway boiler, however, when new, with thinner tubes, that is, one-fourth inch instead of five-sixteenths, and welded up the side instead of being riveted, I have, occasionally, obtained a larger performance than that given in the statement referred to. The result of the experiment in question was

that eleven and one-tenth pounds of water was evaporated by each pound of coal consumed of an inferior kind called *East Adair's main*. The pressure of the steam was carefully kept up during the experiment, (nearly two hours,) at exactly 40 lbs. per square inch, the engine doing its ordinary work, except that the feed-pump was stopped off, and, consequently, no feed-water was going into the boiler, which enabled me to measure very accurately the fall of the water-level in the glass water-gauge; and, knowing the exact internal dimensions of the boiler, the quantity of water boiled away was thus clearly ascertained with sufficient exactness for a short experiment: at any rate, the result was as near the truth as the quantity of coal used could be measured, considering that the quantity of fuel on the bars had to be *estimated*, to be equal at the beginning and the end of the experiment. At that time (1850) no such thing as an absolutely correct water-meter, at a moderate expense, for *boilers*, was in existence; that desideratum, however, now appears to be attained by the invention of Mr. Kennedy, of Kilmarnock. So important an appendage to steam-boilers as a correct *boiler-meter*, constantly registering the quantity of water boiled away, has been long looked for and longed for by every honest engineer. Besides being a continual check against that neglect of the feed-water which too frequently results in explosions, it will also be a serviceable check on the extravagant expectations often raised upon the statements of interested patentees of their schemes for saving fuel. I do not risk much in predicting that when these meters become more generally known and used, they will produce a revolution in the engine and boiler trade, quite as great as was produced by the first general introduction and improvement of Watt's indicator, by the late Mr. John M'Naught, of Glasgow; an era which makes us now look back to those times of hemp-packed pistons, "never tight," and air-pump buckets, "never meant to draw," as to a long-bygone age, though but few years have elapsed since that barbarous time. And now, by the help of the *boiler-meter*, we hope soon to dispel the present uncertainties of some hundreds of smoke patentees as to whether their plans save seven per cent. of fuel, or *seventy*, although, for aught they know, they are just as likely to do one as the other; but I have a strong suspicion that the best of them,—and I am far from denying that

there are many good ones,—will be found to come nearer *two* per cent. than twenty.*

Reverting to our evaporating experiment at the Gutta Percha Works; the pressure being forty pounds, the temperature of the steam, and, of course, the water also, was at about 288° Fahr. In order to compare with the ordinary practice, the evaporation of 11·1 to 1 must be reduced to what it would be were the boiler supplied at the ordinary standard temperature of 100°, which, by the Admiralty rule for that purpose, assuming the latent heat of water at 1000° is as follows:—

$$\frac{(1212^\circ - \text{actual temp. } 288^\circ) \times 11{\cdot}1}{(1212 - \text{standard temp. } 100) = 1112} = 9.2 \text{ lbs.}$$

water to one of coal.

It is proper to state that the rate of combustion did not much exceed ten pounds of coal per square foot of grate-bar per hour, and that the experiments were repeated in the presence of several competent witnesses, occasionally reaching a corrected evaporation of ten and a quarter pounds of water to one pound of coal; or, in other words, a Galloway boiler made a common variety of bituminous Newcastle coal, in ordinary practice, go as far as the *best Welch* in a pet experiment with the far-famed Cornish boiler.

In order to arrive at the best proportions to be observed in a boiler of this kind, we have ample experience to rely upon. Besides the experience afforded by the great number made by Messrs. Galloway, both for land and steamboat purposes during the last three or four years,—there is a sufficient number of them in the

* Except, perhaps, 20 per cent. *below par, negative* "saving." But we trust this subject will yet receive, as it deserves, more serious treatment. At a meeting of smoke patentees, called by the authorities of Leeds, some years ago, one, the most notorious of them, whom we will call No. 1, promised 50 per cent. saving in fuel. No. 2, equally well known, promised 60! while others promised 70 and 80!! not being particular to a few per cents., whom we may call, collectively, No. 3. The results are,—No. 1 sent a new steam-ship to sea with this plan, which ship very narrowly escaped the fate of "the President," being, only through the greatest care and discretion of her commander, brought back to Cork, to repair her boilers, *after being nine days out on her way to America.* No. 2 had his plan in operation not far from the Manchester Exchange, which ended in a well-known terrible explosion, killing nine or ten people. While No. 3, an 80 per cent. man, has more recently had one of the most destructive explosions on record in Yorkshire.

metropolis for the purpose of illustration. The dimensions of the boiler at the Gutta Percha Works, above referred to, where the evaporation experiments were made, are as follows:

Length of boiler thirty feet three inches. Diameter of ditto inside, seven feet. Greatest diameter of main flue, four feet six inches inside, by three feet deep, containing thirteen conical water-tubes, each eleven inches inside diameter at top, and nine inches at bottom, which tubes act as prop-stays between the flat top and bottom of this main flue. The entrance to this main flue is by two parallel and similar furnace tubes, each eight feet long, and somewhat *oval* in section, being two feet six inches wide, by two feet nine inches deep. But they are stronger than if they were circular, on account of containing three strong cast-iron bearing-bars for supporting the grate, which act as prop-stays from side to side. The fire-grates are each seven feet four inches long, by two feet six inches wide, containing about three-quarters of a square foot of fire-bar area per horse-power for the 50-horse boiler. Each of the furnaces contained two lengths of fire-bars, the front bars being one inch and those at the back one and a quarter thick, with three-eighths of an inch spaces between them in both cases. This pitch of the bars was adopted without my concurrence, otherwise I should have preferred the front bars, one and a half inches thick, with the same spaces, and the back bars with one and a quarter or five-sixteenth spaces, instead of three-eighths, in order to attain a more perfect combustion of the smoke,—that being the object for which Messrs. Galloway originally adopted the double furnace plan. These grates have since been replaced by Miller's (now expired) patent movable bars as improved by Mr. Annan for Mr. Chanter, the proprietor of that patent, that is, by making every alternate bar, only, movable by hand, instead of the whole set, when each adjoining bar moved alternately in opposite directions, according to the mode originally patented by Mr. Miller. These movable bars, in some measure, answer the same end as the thin bars; that is, of increasing the rate of combustion and, of course, increasing the evaporating power of the boiler, at the expense, perhaps, of a little smoke, which, however, may consist with the most perfectly attainable economical combustion of the fuel.

"Perfect combustion," and the action of a "perfectly smokeless furnace," are very far from being synonymous, or even similar

phenomena, and produce very different, and, sometimes, widely-opposite results, both chemical and physical, not always likely to be recognized by every noisy patentee or pretender who takes his chemistry like his physic, from the pharmacopœia. In some conspicuous instances, at least, the philosophical jargon employed really encumbers the path of science and progress, and, finally, becomes a much greater nuisance than the smoke which these mock-philosophers pretend to subdue.

So far from perfect combustion, and perfect smokelessness, in a steam-engine furnace being identical, they are, very commonly, the antithesis of each other; perfect combustion being the most completely effected when the whole of the oxygen passing through the grate is the most nearly or perfectly used up in combining with the hydrogen and carbon of the fuel, although it may be occasionally accompanied by the *inappreciably* small loss of a few uncombined atoms of the latter substance in the form of smoke or *soot*, which in fact it is, in a finely-divided and impalpable state, merely giving a *black color* to the nitrogen and other useless incombustible gaseous products of the furnace. These products *must* pass off, visible or invisible, at whatever cost, although we question, were it possible to collect all the fuel in a large volume of visible smoke many hundreds of miles in extent, whether it would amount to a single ton of coals. A smokeless furnace, however, on the other hand, when the result of a thick fire, thick bars, and slow combustion, may, and frequently does, occasion a loss of a large part of the carbon of the coal, which passes off by the chimney, only *half-burned*, in the shape of perfectly invisible carbonic-oxide-gas, thus creating a dead loss of 25 per cent. in coal. This evil, however, admits of prevention in these double furnaces, and by other simple means.

As to the strength of this boiler, the furnace-plates are of Low Moor iron, three-eighths of an inch thick, the flue and shell of the same thickness of the best Staffordshire, and the flat ends one-half inch. The ordinary working pressure of the steam being about thirty-five pounds per square inch, gives a strain of about 4000 pounds on each square inch sectional area of the iron in the circular part of the shell, leaving a surplus of about 1000 pounds per square inch greater strength in that part of the boiler, which is equal to withstand a higher pressure of steam by 25 per cent., and we may be

still assured that the boiler is not strained to one-sixth of its ultimate power of elasticity, that being taken at about 20,000 pounds per square inch of sectional area.

One object of adducing this case of a Galloway boiler at such length, is to show the propriety of using a much higher pressure of steam than has hitherto been usual or much practised in marine boilers, as well as the safety of those boilers for that purpose; and it is proper to state that the strength of the plates as above given is now found, after a trial of five years' constant work, amply sufficient for every purpose, with engines requiring steam from forty to fifty pounds pressure. This boiler has been during that time which may be said to be nearly equal to ten years, working the ordinary day-work in a regular factory, and under the various vicissitudes commonly attendant on night and day working, it has not sustained a single casualty, and not even a leakage of any kind that could be discovered after the most careful inspection. My own personal examination was particularly and frequently directed to the upper end of the vertical tubes where the flame impinges with its greatest intensity, immediately after passing over the furnace bridge,—this particular part having been pronounced by all practical boiler-makers as being the most vulnerable point in other vertical-tube boilers. I, in consequence, subjected it from time to time to the most scrupulous examination. The result, on the whole, has been so satisfactory that I now venture to recommend this plan of boiler as pre-eminently suited to marine purposes. Should any doubt remain on the mind of any engineer as to the power of the "*elliptical*" flue, as it has been wrongly called, to resist collapse from 150 lb. pressure, that doubt can only apply to the segmental or semicircular portion of its sides,—the flat top, supported by any adequate number of tubes, being impossible of collapse. There is one exception, which may be stated in order to remove such doubt. And as exceptions sometimes prove the rule, this one will serve to corroborate our opinion, already expressed, as to the much greater strength of this form of boiler than those of the "Pacific," "Baltic," and others with longer vertical water tubes, and which *therefore have the sides of their main flues* of greater depth, and consequently weaker. The exception is, that only a single case has occurred in the whole range of Messrs. Galloway's extensive practice in the manufacture of those

boilers where collapse in the flue took place; and on that occasion, as appeared from the report of another engineer, was clearly attributable to this portion of the flue having (from some unaccountable caprice) been made nearly flat, or at least with a very great radius of curvature. The proper curve, however, for this portion of the flue, it is very clear, should be a semi-cylinder, or a portion of one, of the same radius as the top of the furnace-tube, when of the same thickness, they being both subjected to the same pressure.

Besides other and larger boilers on the Galloway plan at the Gutta Percha works, I have also erected several of various sizes at other places, in which perhaps better proportions were attained.

Two such boilers have been working for nearly four years past at the London Zinc Mills, more successfully, perhaps, and with greater economy, than has ever before been obtained with any other description of boiler under similarly unfavorable circumstances. The dimensions of these two boilers are precisely the same, and are as follows: Length twenty-four feet, diameter seven feet. Greatest diameter of main flue, five feet seven inches: which flue contains twenty-one vertical water tubes, eleven and a half inches diameter at top, six inches at bottom, and two feet ten inches long. These tubes are three-sixteenths thick, *welded*, and placed zigzag fashion, so that a man may creep easily along each side of the flue and sweep in amongst them. The boilers are placed upon a number of fire-brick blocks, or short columns, eighteen inches high, nine inches diameter, and eighteen inches apart,—so that the whole of the lower half of the external shell of the boiler, except where it rests on the columns, is exposed to the smoke and hot air in the flame-bed. The flame and smoke thus pass through among these columns immediately after passing through the main internal flue-tube, and then *dip* underneath the ash-pit in order to pass into the chimney-flue. Consequently the products of combustion, after proceeding from the furnaces, make *but one return* to the front of the boiler before passing off to the chimney, which happens to be situated near the front end of the boiler. The fact of the very great economy of these two boilers with this mode of setting, so very opposite to the Cornish, and indeed the too usual system of several returns of long winding flues, to which system it is in my mind utter condemnation, would justify

any one, cognizant of this case, to set up such boilers in the direct manner, or without any return flues whatever. This circumstance shows the suitability of these boilers for marine purposes where no external flues can be admitted.

The four furnaces of these two boilers are each seven feet six inches long by two feet nine inches diameter, and two feet eleven inches deep,—composed of Low Moor plates five-sixteenths thick. Each of these furnaces contained three lengths of fire-bars, each about two feet two inches long, half an inch thick, and three-eighth-inch spaces between them,—making about two-thirds of a square foot area of fire-bar surface for each nominal horse-power of the boiler, that being called fifty-five horse.

The external circular shell of the boiler is three-eighths of an inch thick, and the ends seven-sixteenths of Staffordshire plates, "Thorneycroft's best best crown iron." The flat ends are stiffened by angle irons riveted across from side to side, midway between the flue and the top, and from these proceed stay-bars six feet long, riveted in a sloping direction to the top of the boiler. Besides these, each end is further strengthened by four "gusset" or angular plate stays. The angle irons round the ends are three and a half inches broad, and the rivets are two inches pitch. Each boiler is surmounted by a cylindrical horizontal steam "dome," ten feet by three feet, with curved ends, the same thickness of iron as the boiler. This dome is riveted to the boiler by two cast-iron necks or short pipes, ten inches long by eight inches diameter. To these domes the steam-pipes are attached. One five-inch flat disk lever safety-valve, and one glass water-gauge, is attached to each boiler, but no float-gauge nor self-acting feed.

These two boilers were employed to drive two forty-horse engines of the ordinary Boulton and Watt's construction, made by Peel, Williams and Peel, of Manchester; thirty-four inch cylinders, six feet stroke, and twenty turns a minute; working together a little over 200 indicated horse-power, which they ordinarily did with less than three pounds of coal per horse-power per hour. The steam, being thirty-five to forty-five pounds in the boilers, is *cut off* by the governor and double-beat throttle-valve, instead of a separate expansion-valve, at an average of about a third to half the stroke.

It is perhaps useful to mention that the peculiarly sudden action

of this double-beat or equilibrium-valve, when used as a *throttle-valve*, has always a tendency to cause priming, much more than the ordinary spindle throttle-valve of Boulton and Watt. This, together with the nature of the work carried on,—that of rolling thick lumps of metal, called, significantly enough, "breaking-down," and thin sheets called "finishing," where very great irregularity of resistance is inevitable,—involves the necessity of keeping the steam very much higher in the boiler than is required in the cylinder: the steam in the cylinder seldom ranging so high as twenty pounds per square inch, while in the boiler it is from thirty to forty pounds. The ever-varying resistance caused by these lumps and sheets of metal passing through two, three, or four pair of rolls, at the same time, is one of the unfavorable circumstances for economy before alluded to.

Another circumstance, unfavorable to very great economy in this case, was the draught, which, although the chimney is of sufficient elevation and capacity, was much injured by communication with other furnaces and fire-places, some of them *open* ones, which, without great care in, or *total absence* of stoking or *stirring* the fire, made it impossible to prevent some smoke at particular times, especially after the fire-doors had been thrown open, and the furnace too much cooled. Although valves were applied for admitting air at the bridges of the four furnaces of these boilers, by which all dense smoke was thereby entirely prevented for a period of three or four months, and a certificate was obtained from Sir Richard Mayne, the chief inspector under the Metropolitan Smoke Act, to that effect, yet no sooner was there an occasion to change the fireman, for *a more industrious stoker*, than the smoke again appeared, and the owner was convicted, unjustly, as I think, in a penalty under Lord Palmerston's Act. It is unnecessary to add that the greatest economy of these boilers in fuel was *before* the Smoke Act came into operation. In addition to this, the situation of the boilers was such as necessitated the "dipping" of the flue considerably, in order to enable it to pass beneath the ash-pit, which is well known to be extremely detrimental to draught. Notwithstanding all those drawbacks against the probability of a good performance with, at that time, nearly a quite new kind of boiler, these boilers have continued to work four years without mishap or difficulty of any kind—nearly two years of that time night and day—at the same extremely economical rate.

More practical reasons of the like kind might be here given; but what has been already advanced may be considered sufficient to warrant the conclusion that this plan of boiler might at once be applied as a marine boiler, with the greatest propriety and moral certainty of success. For this purpose the boiler will require very little modification from the form indicated by the above description If any deviation be necessary, I would advise that for 60 or 70 lbs pressure the diameter should be reduced to between five and a half and six and a half feet, and, to meet the exigencies of working with salt-water, besides using the ordinary surface "blow-off," and other similar appliances,* we would make all the plates one-sixteenth of an inch thicker throughout. If required to work nearly or quite up to the maximum pressure of 100 lbs., then all the parts admitting of it should be double riveted, and the rest *welded*.

## THE EXHIBITION BOILER OF 1851.

In recommending that the diameter of a high-pressure Galloway boiler should be about six feet, it is not without due consideration, and considerable experience of various precedents that I offer this recommendation. One such boiler may now be referred to, belonging to the West-Ham Gutta Percha Company of West Street, Smithfield, by whom it was bought of the Commissioners of the Hyde Park Exhibition of 1851, where it had been worked during the six months that the Exhibition was open. And, although only one of *nine* boilers of about equal power used for the purpose, it supplied, as nearly as could be estimated, about one *third* of the whole of the steam used in that building. To young engineers, who usually take theory before practice, it may be as well to state that my reasons, when consulted on the subject, for fixing on six feet as the most fitting diameter for this exhibition boiler, were, in the first place, that with that diameter, according to the rules already given by me, a three-eighths of an inch plate is of ample strength for a working-pressure of 40 lbs. per square inch; that

* Lamb's "Surface blow-off apparatus," as described in Murray on "Marine Engines," 1852, or my Boiler-Cleaning Machines, as described in my Essay on Boilers in 1838, and first figured in the Artisan Club's "Treatise on the Steam-Engine," in 1844, may be used indifferently, as they are substantially the same thing intended for different purposes: the object of the former being to prevent *scale*, and that of the latter to prevent *priming*.

being the steam-pressure recommended by Sir W. Cubitt, and the other commissioners, not to be exceeded, and from whom I obtained at last, with some little perseverance, their consent to *exhibit* this boiler, a difficulty created through some mistake, by which four boilers of a different kind had been previously ordered. It was then erroneously supposed that those four boilers which were of the multitubular class, though without fire-boxes, blast-pipes, or large chimney for draught, would have furnished an ample supply of steam for all the purposes of the exhibition; but in this power, as the event proved, they were utterly deficient, not producing even half the quantity of steam required, so that this Galloway boiler was considered only as a supernumerary one,—a circumstance which gave a very instructive lesson to the railway and other engineers who had the principal share in managing the preparations for working the machinery on that occasion; and the result was that *four additional boilers* had to be supplied in great haste by the same contractor, making in all eight of the multitubular variety, and one Galloway boiler, before an adequate supply of steam was obtained. Although had the architectural and decorative portion of the Commissioners consented to the erection of a brick chimney, which would have been quite in keeping with the engineering and scientific object of the exhibition, instead of *nine* boilers, any *three* of them would have been sufficient, besides giving an excellent opportunity of exhibiting a variety of smoke-burning inventions which were thereby virtually ignored. As it was, there was a petty exhibition of locomotive chimneys, a few feet in height,—with one exception, the funnel of a marine boiler, only twenty feet high, which, in spite of some opposition, I succeeded in having erected to the Galloway boiler we are now describing.

The pressure of the steam being limited to forty pounds per square inch, a three-eighths of an inch plate will only have a tensile strain upon it of something less than 4000 pounds per square inch, sectional area of the iron. The formula for the strength of boilers which I usually employ is, $p = \frac{2\,st}{d}$ where $s$ is the strain which, in this case $= 4000$ pounds, $t =$ the thickness of the metal in inches, $= \cdot375$ or $\frac{3}{8}$, and $d =$ the diameter of the boiler, 72 inches, or,

$$p = \frac{2 \times 4000 \times \cdot375}{72} = 41\cdot6 \text{ lbs.}$$

will be the pressure of the steam allowable with these dimensions; and I have no doubt whatever that double that pressure might have been put on with perfect safety, so far as the tensile strain on the circular portion of the boiler is concerned.

Another reason for the particular dimensions of this boiler was, that, besides knowing well what a three-eighth plate will bear, it is so very much used that the proper thickness for securing the best workmanship can readily be obtained.

There needs, perhaps, no excuse for having made this boiler "stronger than strong enough," seeing that it was to be erected in the close vicinity of so many thousands of persons, daily assembled in the exhibition building, which was, of itself, a matter of no little responsibility; for it was considered good policy not only to be perfectly safe, but also to enable the general public to feel themselves safe, by an assurance of a surplus of strength so far beyond any possible requirements.

For ordinary commercial purposes, however, where people generally know what they are about, as well as for warlike and other government purposes, where they *ought* to know, if anywhere, this very inordinate precaution is out of place. And although I have, both by precept and example, recommended, in common with many other engineers, 4000 lbs. for "best" Staffordshire, and 5000 lbs. per square inch strain of Yorkshire iron, as a safe rule to be adhered to by boiler-makers, I am now inclined to modify that opinion. By fixing too low a standard for strength of iron structures generally, the result has been to induce the manufacture of very inferior and low-priced qualities of iron, which are substituted for the best in many situations where detection of the inferior quality is difficult; and, so long as such inferior qualities reached the low standard required for the best, at a much higher price, an inducement is gradually being created among boiler-makers to believe that, in many instances it is only "the *name* of the thing," which their customers are desirous of paying for. Hence the various designations of "best" and "*best best* iron," although the latter, in some cases, signifies the *worst* of two or three qualities made at the same place. As three-eighths of an inch is a kind of standard thickness to refer to, and the kind called "Thornecroft's best crown" is so well known, it is proper to state that, not only has the boiler already referred to been working

at from 50 to 60 lbs., but several other boilers of the same kind of iron, same thickness, made by the same makers, and in every way similar, except in being one foot more in diameter (which would be equivalent to an increase up to from 60 to 70 lbs. upon this six-foot boiler,) have been working nearly the same length of time, and they are working now with perfect impunity, at the same pressure. Those boilers were all tested at the injudicious pressure, in my opinion, of "*three times their working-pressure.*"

There is an universal prejudice among engineers in favor of this "treble proof" of the strength of a boiler. This exhibition boiler, for instance, was thus proved, in the presence of one of the Royal Commissioners, at 150 lbs. per square inch, which pressure, in the Commissioner's and the maker's opinions, was required to justify them in working it at 50 lbs., although, in an ordinary case, 120 lbs. would have satisfied them when the working-pressure was intended to be only 40 lbs. Now, I am not going to contend that the least injury was likely to be sustained by this particular boiler exposed to so severe a strain; but I wish to point out the absurdity and injurious consequences likely to arise from the prevalence of such a dogma when applied to very high pressure, however safe it has always been at low ones, say under 10 lbs., or, at most, up to 20 lbs. per square inch.

If, instead of moderately good Staffordshire plates, capable, we may suppose, of bearing a tensile strain of twenty tons per square inch section before breaking, we have a boiler to test made of an inferior quality of iron, say only capable of supporting sixteen or seventeen tons, which was found by Mr. Lloyd to be the ultimate strength of the iron of the boiler of the "Cricket" steamboat that exploded on the Thames, in 1847; and if as was proved by Mr. Lloyd, in that case, by direct experiment on the corresponding boiler, every way similar to the exploded one, namely five feet diameter and three-eighth plates, that the latter was severely strained close to the bursting-point, and permanently injured by the application of 136 lbs. per square inch, giving a reduction of about forty per cent. for the riveted, below the original, or solid plate, as tested by him, in strips of two inches broad,—we have only to suppose that our exhibition boiler had been of the "half-penny boat Cricket" quality, and if tested at three times the intended pressure, or 120 lbs., which it might have passed safely,

perhaps, *once*, and afterwards worked, without suspicion, at 40 lbs., although in reality, *weakened* by the process so much as to become dangerous, even at sixty, and it might explode at half-a-dozen or so pounds higher pressure. If such a result may follow such a practice, what, it may be asked, would be a safer mode of proceeding? I answer, from the results of my own practice, as follows: I would have taken a mean point in the above supposed case, between 40 lbs., the working-pressure, and the estimated strength of the iron, say 140, which would be at 90 lbs., and make that the point at which to test the boiler. That is not much more than double, in fact, 120 per cent., above its working-pressure, namely 50 lbs., as well as being also 50 lbs. below the estimated strength of the iron; and supposing the life (as it is called) of such a boiler to be estimated at five years, then this proof test ought to be reduced by equal instalments of 10 or 15 lbs. each year. Now, who will say that, if such a course of procedure, or some similar one, had been made compulsory by legal enactment, before the "Cricket" explosion, that that "accident," and many others, would not have been avoided? But as we are, so far, only dealing with probabilities, we may take the actual pressure used in the "Cricket," namely, working-pressure, as proved at the inquest, 66 lbs., the bursting-pressure, as proved by Mr. Lloyd's experiments, 136 lbs., which gives a mean of $\frac{136 \times 66}{2} = 101$ lbs. for the testing-point, or about fifty per cent. only, above the actual working-pressure. By this, it will be seen how much safer a test of this proportion would have been than the treble test.

I have stated in a previous work that a test of double the working-pressure was *amply* sufficient; but I by no means wished it to be inferred that such a test should be considered to be necessary, or useful, except at moderately low pressures. In my notes to the edition of "Tredgold on the Steam-engine," published in 1852-3, I regret having overlooked what I consider a dangerous error in that author. Although he admits that double the working-pressure is a sufficient test for low-pressure boilers, he states that "it becomes insufficient in high-pressure boilers, because they have a smaller amount of steam room," and actually gives a formula for calculating the excess of strength which he would give to a boiler on that account, saying, "If one boiler contains twenty cubic feet

for each horse-power, and another only ten, the boiler with only ten feet of space should be of twice the strength." It is scarcely necessary to point out how TREDGOLD confounds, here, two entirely different objects; one, the prevention of injury to boilers by excessive strain in testing them; the other, the having such an excess of strength as "to provide against accident in the event of the valves being out of order," &c. (Page 268.) Trusting that these remarks may in some small degree atone for the share I took with others much more competent in delaying a little longer the descent into oblivion of this heterogeneous work of "Tredgold on the Steam-engine," I shall return to the description of the Galloway exhibition boiler.

If, as I think I have made manifest, this six-feet boiler of three-eighths Staffordshire iron, with the ordinary lap and single-riveted, be equal to a working-pressure of 70 lbs. per square inch, then it may safely be asserted that a boiler of the same shape and dimensions of Low-Moor or Bowling Iron, one sixteenth of an inch thicker, and double-riveted, *welded*, indeed, where necessary, and judiciously stayed, would be abundantly safe to work in a steam-ship at the maximum pressure of 100 lbs.

That such a boiler for such a purpose would be very decidedly superior in every respect to any form of marine boiler at present in ordinary use for *large* steam-ships, scarcely admits of a question with any one understanding the subject; and those who do not may have the clearest of proofs in the performance of the land boilers I have referred to, as well as that of many others on the same principle, now spread all over the country.

We contend for the adoption of the correct principle which we know that these boilers contain. And as certainly as is the truth of any common rule in arithmetic demonstrable to those who consent to examine the proof, so certain is it in my apprehension that any expedient, which supersedes the present flue and multitubular marine boilers, will very considerably accelerate the passage between this country and America. If this be accomplished even only by a single day of the nine that is yet required, a great object will be attained for the progress and welfare of the people of both countries. That such an achievement is a point worthy of any man's ambition, we need not insist on,—or that of any number of men, on either or on both sides of the Atlantic. To shorten the

way to America, by reducing the time now occupied at the rate of only ten per cent. per annum for the next four years, would solve a problem of immense social importance. It would in four years time lay us alongside our friends and brothers in the United States in SIX DAYS! That this will yet be accomplished, there can be little doubt! Experiments in fact are already in progress with this end in view. To reach New York in six days is an object far above any partisan or even national views, nor is the benefit wholly measurable by the pecuniary or commercial advantages attained. For it is by such achievements that nation is to be knit to nation by bonds of undying brotherhood, and the advent is to be hastened of that peaceful kingdom, the clarion of whose renown, and the majesty of whose sceptre, will command the joyful homage of mankind.

On a subject of such vast interest as a material improvement in the art of steam-navigation, every engineer, sailor, and shipwright, has some crochet of his own. I confess not to be singular in this respect, and some of my plans of improvement have been not confined to paper. They have embraced both engines and propellers, but have principally been devoted to boilers and to *furnaces.* Though certainly I have never been guilty of trying to help a ship on her way to America by *burning smoke*, the miscarriage caused by which was subsequently visited upon unoffending parties.

The merit of that abortive attempt lies with Mr. Charles Wye Williams, so well known for his nostrums in smoke prevention, and the untiring energy, usually appertaining to such adventurers. That a properly constructed *Fire-feeder*, which would supply the furnaces without involving the necessity of opening the fire-doors, or admitting air except through the fire-bars, would be of great advantage, and abolish the slavery of the stoke-hole, no one can deny. But that would be irrespective of any smoke-consuming or preventive properties it might possess; which, however desirable, should not be allowed to engross our first attention. Feeding and stoking the fire, however, have long been accomplished by very simple machinery, on the principles of Stanley and Walmsley, and Miller. All the three inventions are now public property: the patents having long since expired; and, alas, the patentees, whom I knew well, have expired also. They were thoroughly practical

engineers, and their inventions were entirely successful on land, as they would have been on sea also had an opportunity been afforded for their trial. Those appliances to a suitably constructed marine boiler it is underrating them to say would increase the boiler power of the steam-ship by ten per cent., as they have always done that of the *steam-mill* on land by double that amount.

These, and many such equally valuable inventions, not the speculations of mere "science-mongering" amateurs, or paper engineers, but the actual tried and proved productions of practical operative mechanics, lie at hand ready for application to every emergency that can possibly arise in the development of that improvement of steam-navigation now so urgently required.

"Where there is a will there is a way," is an axiom in mechanics, as in other things, if *there be money*. As a sample of the mode of proceeding in the choice of an improved boiler, let any plain business-man or merchant—he need be neither an engineer nor man of science—obtain a ten-minutes' interview with the manager of the West-Ham Gutta Percha Company, at their extensive works in West Street, Smithfield; or let him go to any other factory of which there are several in London, where the Galloway Boilers have been working for several years,—for I perhaps take a liberty in referring to this one more than others, which I have done from its central position in the city, and its having been so well known for many years as the Iron Works of the late Alexander Galloway and Sons, the eminent engineers, formerly of this country, but now of Egypt. He will there see the original exhibition boiler at work, which, I have the authority of Mr. Walter Hancock, of the Gutta Percha Company for stating, has been working under his superintendence almost uninterruptedly four or five years since the closing of the Exhibition,—a great portion of that time working night and day, and frequently at the extreme range of pressure; this, too, without any deterioration from use. A few minutes' inspection will bring entire conviction of the accuracy of what we state. The visitor will there see a greater quantity of steam produced by a comparatively small boiler, which might if necessary be fixed aboard a steam-ship, and at work in a few days,—at a greater pressure by two or three times over than is now generally attainable in the present marine boilers: withal, too, at the cost of a much less quantity of very inferior coal than is at present

required perhaps by any other description of boiler, even on land. He will see all this done without the fussing, stewing, and sweating of the present barbarous stoke-hole practice aboard ship, which too many people think a necessary concomitant of all marine steam-engines. On the contrary, he will see the work done quietly, with cleanliness and easily; and the black smoke "perfectly consumed" into the bargain, without the intervention of any smoke-consuming apparatus of any kind, patent or otherwise,—no air being admitted to the furnace except what passes through the fire-grate; and he will instantly ask himself, is all this applicable or possible in a steam-ship? My answer to such a question is, that it certainly is, excepting merely the tall, brick chimney, the want of which would only affect the ability to consume inferior fuel, or the prevention of a little smoke, but which qualities, if thought important, may be easily retained by the introduction of a small blowing-fan.

### THE ELEPHANT BOILER.

Having disposed of the question, how steam can be best obtained at a pressure, or nearly up to a pressure, of 100 lbs. per square inch, and that in boilers with internal furnaces, thereby permitting their use in *wooden* ships where necessary, we come now to the requirements of 100 lbs. pressure and upwards. For this purpose we anticipate the necessity of an iron ship. The reason for this is, in the first place, that to enable boilers of a given thickness and strength of material to stand a double pressure, they must be just half the diameter: therefore it is necessary to have external instead of internal furnaces. It is an inevitable law that the strength of the shell of a cylindrical boiler is inversely as its diameter: or, in other words, if we find a 6-foot diameter boiler with a three-eighths shell to stand 60 lbs. pressure, then we may be assured that a 3-foot boiler will stand 120 lbs. pressure, or nearly so, under the same circumstances. In the second place, the full value in heat, from any kind of fuel, cannot be obtained without the intervention of fire-brick, or other non-conducting substances, but with which it would be quite impracticable to line the present marine-boiler furnaces, or, in fact, almost any internal furnace for commercial purposes: although we recol-

lect the case of an iron fire-box boiler, erected to heat a new church in Manchester, some years ago, having its steam-generating power nearly doubled by simply putting in a fire-brick lining round the fire-grate,—thus preventing the refrigerating effect on the fuel and flame produced by the close contact of the water-casing and bridge of the fire-box. Many good smoke-burners have been made simply by inserting a few fire-bricks in this way, thus, as it is called, *concentrating* the heat.

By making a small boiler, we make a strong boiler; and by making a brick furnace, we make a hot fire.

In adopting the elephant principle for a marine boiler, we get both these advantages, a small diameter and an external furnace. But, besides that, we get a large width of fire-grate, and the convenience of using firing-machines. Moreover, as the resistance is more dependent on the width of the ship than its length, it is incumbent to occupy the entire beam dimensions of the vessel without the intervention of water-legs between the furnaces, if we require the maximum power of the boilers, when they are arranged transversely across the ship. This the elephant boiler gives us the means of doing with advantage. A range of three or four boilers may be thus made to occupy the whole breadth of the vessel, with nothing beyond a thin fire-brick wall between the furnaces. The proper physical management of the furnaces is a matter on which far more reliance ought to be placed for increasing the power of steam-ships than is dreamt of by any of our "chemically considered" combustion patentees. It is not undervaluing science, but the contrary, to maintain this,—in which I shall be joined by Faraday, as I was by John Dalton when living. To encourage a fireman to work by tact and judgment,—not by empirical rule,—to become dexterous, watchful and discriminating, is surely of more use than to cram him with the jargon of science, which would leave him as useless a member of society as those who are already thus distinguished. Chemical diagrams, and the atomic system of philosophy, will give little aid in keeping up the steam, and those who are chemists among stokers, and only stokers among chemists, will lend little aid to the advancement of either art.

Although the elephant boiler is perhaps more popular in France, and on the Continent generally, where it was introduced by Woolf

himself many years ago, it is much used in and about London, principally at flour-mills, being considered a strong and safe boiler, but *smoky*. Hence, it is often used with Welsh smokeless coal, but it is well adapted to Jukes's, Hall's, or other smokeless fire-feeding machines. I consider that *three* instead of *two* lower tubes are objectionable, as they are in that case too small to be easily kept clean. Such boilers are not much used in the manufacturing districts, where they are known as "French" boilers. But there are some good examples in Lancashire, the two lower tubes being made large enough for a man to get into to clean. They have been commonly made by Messrs. B. Hick and Son, of Bolton, to go with their engines abroad. Some erected by them at Barcelona, in Spain, were of well-considered proportions, being 24 feet long, the main body of the boiler 4 feet diameter, and egg-ended; the two lower tubes each 2 feet 2 inches diameter inside, with only two or three inches betwixt them. The vertical connecting-pipes, or water-legs, were 18 inches diameter; and the fire-grate was 5 feet wide by 6 feet long.

The most powerful boilers of this kind I have seen were erected by the same makers at the "India mill" of Lees, Kershaw and Co., in Stockport. They are 35 feet long by 5 feet diameter in the main barrel; the two lower tubes are 2 feet 3 inches diameter; connecting-pipes 16 inches diameter, and 2 feet 3 inches high. The main barrel of the boiler is *flat-ended*, and contains a fire-flue 2 feet 3 inches diameter, which is the most objectionable feature as regards safety. Nevertheless, these boilers are worked very satisfactorily with a pressure of 64 lbs. per square inch, and using little more than 40 tons of coal per week. Two of them are capable of exerting about 500 indicated horse-power, driving cotton machinery, &c. They consume about 3 lbs. of coal per indicated horse-power per hour, by means of a pair of compound engines of 8-feet stroke, making 16½ strokes per minute. One engine has the large cylinder 50 in. diameter, and the small one of 23 in. The other engine has the large cylinder of 52 in., and the small one of 25 in. The steam is cut off at 5¾ ft. of the stroke. These boilers occasionally work in conjunction with double-flued cylinder or Cornish boilers, 6 feet diameter, with which they contrast very favorably. The fire-bars are three-fourths of an inch thick, and the rate of combustion quick, say

10 to 15 lbs. of common coal per square foot per hour. The draught is produced by a brick chimney, 65 yards high by 6½ feet wide, inside, at top, and 1 inch per yard batter outside. The above data were collected in 1848–9, since which the boilers have been supplied, I believe, with my cleansing-machines, and with Dean's double fire-feeding machines. They have also been covered with felt, &c.: all, of course, tending to produce a still more economical result. I offer this as a sample, and not by any means a solitary one, of the engineering economy of Lancashire, which I would submit to the consideration of my engineering friends in Cornwall, with their lightly-loaded engines and superior coal.

I scarcely need add, that none of the new smoke-burning schemes have any share in producing the economy at the India mill, unless Mr. Dean's excellent fire-feeders be classed among such. They, however, do not operate by letting in *cold* air against the boiler bottom, but by keeping it as hot as possible, and the fire-door shut. At any rate, they cannot be said to be benefited by any thing that has come out of Lord Palmerston's Smoke Act. At another mill, belonging to the same firm in Stockport, previous to the erection of this one, having three large engines, also, doing about 500 horse-power by 120 tons of bad coal per week, several then well-known plans of smoke-consuming, or prevention, were tried successively without any appreciable saving of coal,—some of them at an expense of some hundreds of pounds. The list of inventors' or patentees' names, as given to me by a member of the firm, comprised those of Rodda, the two Halls, Chanter, Armstrong, and Williams. My own plan, in this selection, it is only proper to state, was the only one that cost them nothing, being a careful system of charging the fires at the back, which I introduced at the same works, the Mersey mills,—then belonging to another firm,—many years previously. This mode of firing is described in one of my "Tracts on Steam," also in the Artisan Club's Treatise on the Steam-Engine.

I might here ask what possible objection could be raised against taking so simple and efficient a boiler as above described, and of which the performance can be so easily verified, and place it in an iron steamer, at once, and withal at so cheap a rate (from £35 to £40 per ton of Low-Moor iron), in place of the present mulitubular marine boiler, costing *double* the expense?

In referring to Arthur Woolf as the inventor of boilers composed of systems of comparatively small water-tubes, and which he was mainly conducive to bring into use between 1810 and 1820, it is not to be understood as applying exclusively to the particular form of boiler *patented* by him. That boiler was, for reasons applicable to most patented articles, not the best specimen of the invention, and it was deficient in proper circulation of the water. Woolf's boilers were really not successful until they took the form of the Elephant, or French boiler, the latter designation being applied in consequence of its being first introduced, if not also first made, in France, by Mr. Woolf himself.

I rather wish to consider him in common with Oliver Evans in America and Dr. Alban on the Continent, as the propounder of a principle of construction of perfectly safe boilers for very high pressure, that of confining the pressure entirely within tubes of comparatively small diameter. That system of construction was almost a necessary concomitant of the introduction of the compound high and low-pressure engines by Woolf and Edwards, which engines have been, since their time, extensively made by Hall, Humphreys, Rennie, Hick, and others. The great success

Fig. 92.

of these engines in *extreme* economy of fuel with *extreme* high-pressure steam, has, for some time past, created a great demand for suitable boilers; and that demand has been recently met, in an excellent form of boiler, partly on Woolf's principle by Dunn, Hattersley, and Co., of Manchester; but in which the circulation of the water is more perfect than in Woolf's original plan.

The patent boiler of this firm, termed by them "the Duplicate or Retort boiler," is represented in the annexed cut.

It was first introduced to public notice at a meeting of the Institution of Mechanical Engineers at Manchester, and has since been tested to work with perfect safety at 250 lbs. per square inch. One of the retorts, nineteen inches diameter, having been purposely pressed until it burst, was found to sustain the extreme high pressure of 525 lbs. before it gave way.

This boiler appears to be formed principally with a view to portability and lightness, for convenient transit, in which it certainly exceeds all others. Besides its great strength, it has, in my estimation, other valuable features, such as its capability of admitting any modification in size of fire-grate, or of fire-feeding machinery, underneath it; and next to that is the very large proportion of effective heating-surface exposed to the direct radiation of the fire on the grate. It has also the advantage of admitting of the retorts being *turned over*, as they become blistered or worn over the fire, or of being replaced by others farther off, or by new ones.

An attentive consideration of Mr. Dunn's boiler will discover it to possess some valuable peculiarities in regard to the deposit of mud, which, so long as the water chambers are connected, must necessarily lodge principally in a few of the retorts farthest from the fire-grate. The retort at the extreme end will, in fact, act as a mud vessel or cleaning-apparatus for the remainder. A most important purpose will thus be effected, which I hope to have an early opportunity of comparing with previous inventions for the same purpose before pronouncing a decided opinion, content for the present in remarking that the same conditions which constitute the last retort of the series an efficient mud-collector, also constitute it the most appropriate portion of the boiler at which to supply the feed-water, and thereby act as a heater to the latter. To this portion of the boiler Mr. Dunn attaches a cock, or other means of blowing off the sediment frequently. Of mud-collectors and water-heaters combined, there are a great many varieties, among which we may mention that of Mr. E. Green, of Wakefield, as one of the most successful in extensive use; but I have never seen any that in simplicity and compactness approaches this of Mr. Dunn's, and I would say it is applicable to other boilers, the Cornish in parti-

cular, as well as the retort boiler, of which it is a component part.

Of cleaning-machines that are applicable and effectual in every situation, to all qualities of water, and every kind of boiler, locomotive, stationary, and marine, there is only one variety—that with the *internal* collecting vessels, agitator, and blow-off cock—that can prevent *priming*. And this they do most effectually under all circumstances, if there be room in the boilers to fix them. Nothing can be of greater importance in improving the steam-engine than the effectual prevention of priming, and the subject of cleaning-machines is, on that account, alone almost entitled to some future volume of such a work as this to itself.

Fig. 93.

Having recently learned that some *sea-going* vessels contained Messrs. Galloway's conical-tube boilers, I immediately procured the above sketch from the Patent Office, which, I am informed, represents correctly the boilers in question, although not drawn to any precise scale.

## CHAPTER XXV.

### SMOKE PREVENTION AND ITS FALLACIES.

WHILE the greatest attention has been given by engineers at all times in advancing the steam-engine towards perfection, much less has been done than ought to have been done in improving the construction of the boiler; but least of all has been done for the furnace,—the details of fire-grate, the supply of fuel, and the most important of all, the management of the FIRE, upon the proper operation of which much of the efficiency of the machine is dependent. The business of the "stoker," however subordinate and apparently unimportant, cannot long be neglected with impunity; for, like the organ-blower, he will occasionally let us know that the instrument cannot work without him. That portion of mechanical engineering which concerns the architecture of furnaces has been for so long a period left to the mercy of the operative bricklayer and the iron-founder, who have both done what they could with large quantities of fire-brick, fire-clay, and thick heavy fire-bars, that it has become like certain less agreeable portions of another profession we might name, which the regular practitioner commonly endeavors to avoid, but which there are plenty of "irregulars" ready to occupy. The consequence of this has been, as in the profession alluded to, that this important branch of engineering is so much overrun by quacks and pretenders, as generally to excite a considerable degree of contempt in honorable minds for the section of the arts thus degraded. To these phenomena may now be added the natural effect of the recent alteration in the patent-law, which has so suddenly overwhelmed the community with swarms of great and little monopolists in every direction, and it is not the least part of the swarm which has settled down upon that opprobrium of engineering, the *smoke nuisance*. On this subject every smatterer on science has a theory of his own to uphold. Nearly every ironmonger is now a patent-furnacemonger, and any gas-

fitter is ready to fit us with his patent apparatus for "consuming smoke." Advertising quacks, whose business is puffing, are ready to subdue smoke-puffs, and promise, at the rate of 20, 30, and 40, or any other per centage, in saving of fuel, by adopting their several nostrums, each guaranteed by hundreds of cut-and-dried testimonials. Audacity in this matter is far from being confined to the needy pretender, but stands out boldly bedizened in the canonicals' of science. The style adopted, and the expedients resorted to by these smoke-doctors, are worthy of Dr. Solomon, of Balm-of-Gilead notoriety, or of any other of that band of patriots who request us to beware of counterfeits. The policy pursued is that of *continual reiteration* to induce a belief of incredible statements, or to create faith in such respectability as at least possession of money may give. This we see daily in glaring sign-board announcements. Indeed, some of the most conspicuous and wealthy of those worthies are known to have competed at public meetings in the provinces, in extravagance of pretension, bidding against each other for public favor, by promising a saving of 50 and 60 per cent.! Of the honesty or dishonesty of such representations, it is needless to speak; but I must state emphatically that, having closely attended to every experiment of consequence in smoke-burning for a series of years, I have never yet found evidence of a saving of even five per cent. by any plan of preventing or consuming smoke, however "*perfect.*" And, further, I have found the more perfect the consumption was of smoke, the less was the saving of fuel; or, more properly speaking, a greater consumption of fuel is required in raising a *maximum* quantity of steam *from* the *same boiler* in *the same time*, when the smoke is entirely prevented, than is the case when smoke prevention is not attempted at all. In short, perfect *combustion* is not perfect *economy* in practice, but far from it.

That I have long been convinced of the futility of smoke-consuming furnaces *as a measure of economy*, although I have had, and have still, the strongest inducements of self-interest to endeavor to think otherwise, will be evident, if I transcribe a passage from a work published by me nearly twenty years ago, parts of which had been some years previously drawn up in the shape of reports at the request of various cotton, and other manufacturers, in Lancashire. The work was printed by desire of those gentlemen in

1837, and a second edition was published in Manchester in 1838;* and as it has long been out of print, and as it still expresses my views upon this subject, I believe that no apology is necessary for the introduction of the following quotation:

"SMOKE-BURNING FURNACES.

"In nothing has the philosophical manufacturer or amateur mechanic been so much at variance with facts, and the experience of practical men, as on the subject of smoke-burning. It is perfectly true that the black carbonaceous matter, which usually escapes along with the incombustible gases, and which is the only *visible* constituent of what we term smoke, is all so much fuel; and when *properly* consumed under the boiler is undoubtedly a saving of coal; but it unfortunately happens that the saving is so *inappreciably small* that none who have tried it fairly have been able to calculate exactly its amount, except when it has taken the negative form, which it has most frequently. It is not my intention to speak disrespectfully of any of those who have proposed to save fuel by burning, or '*consuming smoke by combustion*,' as they usually prefer to term it; for they have generally, if not universally, deceived themselves before they led others astray, as the hundreds of patents for that purpose, and the hundreds of thousands of pounds expended over them, amply testify. Patent inventors, indeed, of improved furnaces for 'saving fuel by consuming smoke,' deserve no small share of public gratitude, from the many opportunities they have given us of ascertaining by experiment a great number of practical data, and useful results, which are now available for other more important improvements."

The pursuit of "smoke-burning," in fact, has been the *philosopher's stone* of the present century. Speculative and practical chemists of the brightest intellects have dabbled in it; such men as Rumford, Watt, Dalton, and Henry, were believers in its economy. I cannot speak as to Davy, but it is thought that the predilections of the great living German chemist, who has done so much for the brewing-trade of England, lie that way; at least his foremost disciples

* A Practical Essay on Steam-Engine Boilers, as now used in the manufacturing-district around Manchester. By Robert Armstrong, C.E.

in this country hold to the yet popular doctrine that *sixty or seventy* per cent. of the fuel is to be saved by burning the invisible carbonic-oxide gas, which now escapes from our iron furnaces in Staffordshire.

On this subject I can speak with the more confidence from having had a good deal of practice in directing the application of various patent and other apparatus and methods devised to enable furnaces to consume their own smoke in different parts of this country, as well as in the planning and erection of boilers and furnaces generally in the ordinary way. Up to the passing of Michael Angelo Taylor's Act, nearly thirty years ago, which made smoke prevention in some measure compulsory, little or nothing had been done in the north of England except on the double-furnace system of Mr. Losh, of Newcastle-on-Tyne, patented in 1815. It was more successful with chemical stoves, salt-pans, and slip-kilns in potteries, than with engine boilers. When applied to the latter, it was objected to on the ground that it required a *larger boiler to do the same work*, as well as two fires to do the work of one. I endeavored to introduce it into Lancashire in 1827, but did not succeed until some years after the patent had expired, when the above objection was found to be untenable. The large boiler proved to be a great advantage, and alternate firing was very economical, independent of its convenience for consuming smoke. My mode of applying it was to place simply a wall of fire-brick longitudinally upon the fire-grate, nearly the whole length from the bridge to the dead-plate; but so that both sides could be charged through one fire-door. This method was used in Manchester in a boiler, employed to drive a 40-horse engine, at the Store Street Cotton Mill, belonging to Mr. Wm. Jones. And I afterwards erected similar divided furnaces at the Worsley Flour Mills, belonging to the Earl of Ellesmere, and at several other places, with some improvements, which consisted mainly in restricting the mid-feather wall to one-half the length of the grate, and making the fire-bars at the front of the grate thinner, and with wider spaces, than at the back. The air was generally let in through the sides of the furnace at about half the length of the grate; but at Mr. Jones's, where there was a good chimney, it was admitted by setting the fire-door ajar one and a half to two inches, for two or three minutes after each firing. In cases where the

chimney was low, or had a bad draught from other causes, the supplementary air was forced in over the fire by means of a small rotary fan; and where convenient, this air was in a highly heated state, say at 400 or 500 degrees. In this manner, this species of furnace was worked at the above flour-mill, continuously, with great satisfaction and economy, driving a common low-pressure engine working six pairs of four-feet stones, and other machinery, with about 6 lbs. of inferior coal per indicated horse-power per hour. The proportion of the power required by the blowing-fan was only about half a horse-power. To show the great advantage of either a good draft, or artificial blast, in all cases of smoke-consumption, it is proper to state here that Williams's patent system was previously tried at the same boiler with the same fire-grate area, without enabling the engine to work half the above load; while the same system applied by the same parties to another small engine on the same estate, with a *very lofty chimney*, was moderately successful.

The smoke from the chimney of Worsley Mill, when in full work, was *perfectly invisible*, with the exception of a slight vapor during the time that the fire-door was allowed to remain open, but no longer.

The situation of this flour-mill,—a picturesque spot, about half a mile in front of Worsley Hall,—was such that the mill was nearly hidden from view at that mansion, and its existence would have been unobserved except for the smoke which rose above the trees, before the improvement was applied. When the smoke was prevented, the circumstance accidentally coming to the knowledge of the Earl of Carlisle, when on a visit at Worsley, he took the opportunity of convincing himself of the facts as above related, and on their being reported to the Earl of Ellenborough, then first Lord of the Admiralty, that nobleman at once ordered a similar apparatus to be erected at Chatham Dock-yard. The apparatus was accordingly applied by me to two 20-horse boilers at the lead-mill there, for which purpose I planned the furnaces as nearly as possible a copy of those at Worsley, and the results were very nearly the same. The chimney stood right opposite the windows of one of the royal hospitals, to which the smoke had previously been a great nuisance; but, after six months' trial of the new plan, the chief physician of that establishment reported to the Admiralty

the entire removal of the nuisance, and that the health of the inmates had been greatly improved in consequence. This Report was published in the "Health of Towns Gazette," in 1849. And, as I have just been informed by the Superintending Engineer of the Dock-yard, the apparatus has continued to work uninterruptedly to the present time (1856) with uniform success.*

About the same time several other double or divided fire-grate furnaces were erected, by other parties, at the cotton-works of Mr. John Paley, and at other places, in Preston. These were more nearly on Mr. Losh's original principle, having two separate fire-doors and two ash-pits.

Mr. Howard, Mr. Thomas Hall, and a great number of other parties, have introduced various modifications of double furnaces since the date of Mr. Losh's patent, and more or less successfully. The last modification of the kind I have seen, was erected at a small boiler in the Royal Arsenal, Woolwich, by Messrs. Abernethy and Co., Engineers, of Aberdeen, in 1856. The peculiarity of this plan consists in a jet of fresh air from a pipe on each side of the furnace being admitted alternately, to correspond with the alternate firings by which the smoke from the newly-fired furnace is driven laterally, or horizontally, against the bright fire and flame of the other. This is the principle of admitting air patented by Mr. Spibey, of Nottingham, several years ago, and extensively applied by him to single furnaces; and by this mode of procedure the injury to boiler bottoms from *cold* air rising upwards against them, at or beyond the bridge, is likely to be avoided. I pass

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* In 1839, I introduced the double-furnace system into a steamer, "the William Fawcett," belonging to the Peninsular Steam-Company, and she continued to ply with the furnaces thus altered until new boilers were, I believe, introduced a considerable time afterwards. The arrangement of these furnaces differed somewhat from Losh's plan. Each furnace had a damper behind the bridge, which could be shut when required, and the smoke produced in that furnace had then to descend through a suitable passage, into the ash-pit of the adjoining furnace, which, by this time, had burned bright, and ascending through the fire, mixing with atmospheric air, it was completely consumed. To maintain the necessary draught an exhausting-fan was applied to the chimney. I simultaneously introduced other improvements which very much lessened the consumption of steam, so that, although the boiler was less powerful than before, it was still equal to its work, as smaller demands were made upon it. J. B.

over a great many other plans of double fires, such as Galloway's, Rose's, Fairbairn's, Ormrod's, Hick's, Bristow and Atwood's, and others, as the principle of the whole is nearly the same, and it would occupy too much space to enter into the details.

After Mr. Losh's double-furnace principle, the next smokeless furnaces that came into public favor were those of Wakefield, Parkes, Brunton, and Stanley. The two latter being accompanied by, or mainly consisting of, fire-feeding machinery, which was necessarily expensive, came slowly into use, but they were both perfectly well established previous to the year 1827; and the only reason they are not now more frequently met with is, that they are not well adapted to boilers with internal furnaces. The two former plans, consisting principally of alterations in the brickwork, came more rapidly into use in Lancashire. The smoke-consuming furnaces of Mr. John Wakefield, I believe, had the precedence of the other, in point of time, as I had some pulled down which had been erected by him at the cotton-mill of Messrs. Clogg and Norris, in Long Millgate, previous to 1818, and which I re-constructed with my own improvements in 1830. About the same time, several were taken down at Thos. Hoyle and Sons' print-works, Mayfield, and other places, which had been a much longer time in use. In fact, Mr. Wakefield used to complain to me how Mr. Parkes, "having come after him, stole his ideas" of the split-bridge and air-valve at the back of the ash-pit. However this might be, it is certain that Parkes's system became by far the most popular; a great number of furnaces being erected by him all over the country, from 1820 to 1825, after which they were erected by him extensively in France. In the mean time, however, though the plans of Wakefield and Parkes were originally similar, they soon grew widely different. Wakefield persevered with thin and frequent firing, thin and scientifically constructed fire-bars, well-arranged tools, perforated fire-bricks for heating and diffusing the air, like Williams's, and pigeon-hole bridges; he also paid very great attention to the fireman's art, and he only failed, as he had said, from want of it at last. On the other hand, Parkes's system was carried on by him to the extent of enlarging and deepening the furnaces, so as to hold upwards of a ton of coal at a time. This quantity was usually introduced into the furnace during the first two hours in a morning, beginning rather thin near the bridge, and, as it

became ignited, gradually increasing the thickness of the charge until within two feet of the fire-door, where the coal was filled quite up to the boiler bottom. When arrived at this stage, the combustion was entirely that of the gas from the raw coal. The surface of the fire then formed an inclined-plane towards the bridge, and as the supply of air through the bars was thus cut off, the combustion was kept up entirely by the air through the air-valve at the back of the ash-pit, and the split-bridge, which last was much wider than Wakefield made it, being commonly three or four inches, or more. During the first three or four hours of the day, the air-valve was gradually closed by the fireman, by which time the diminished quantity of fuel in front of the bridge allowed sufficient air to pass through in that way. The air-valve was then shut up, and not opened again during the day. The proper action of the fire was, after this, entirely dependent upon the proper management of the dampers, and in the middle of the day the steam was regulated by the admission of less or more feed-water to the boilers.

The above is a programme of the mode of proceeding with Parkes's system at the cotton works of Mr. John Pooley, of Hulme, where I had most experience with it, thirty years ago; and it is very nearly the same as the mode carried out at the works of Messrs. Horrockses Miller and Co., of Preston, up to within the last few years.

There is no doubt that considerable economy was obtained by this plan, when very carefully managed, with very low pressure steam and very large boilers, even to the extent of getting an evaporation of 7 to 8 lbs. of water to 1 lb. of Lancashire coal; but it was too unwieldy and cumbrous a system to continue in use more than a few years, excepting at the last-mentioned place, where special provisions were made to suit it.

It is not my business, however, in this place, to write the past history of smoke-burning, so much as to describe what is doing at the present time in that direction. With this view, I here insert a brief description of a new form of fire-bar and furnace-grate, which I have had in operation for some time past, at different places, with very satisfactory results. And I expect to be able to present a more detailed account of the arrangements, accompanied by proper drawings of this and other plans of recent construction, in Mr. Bourne's forthcoming work on the steam-engine.

UNIVERSAL "ARGAND" FIRE-GRATE.

Like all other furnaces which burn, prevent, or consume their own smoke by an improved combustion of the gaseous portion of the fuel, the principle of this one depends on the admission of a sufficient quantity of fresh air to the smoky flame of bituminous

Fig. 94.

A new construction of Furnace for "burning its own smoke," as applied to an Elephant Boiler, and adapted to the use of waste timber, slack, and other mixed fuel, by R. Armstrong, C. E., 1855.

coal, as well as to the carbonic-oxide gas produced by a thick fire of coke, or from Welsh coal or other non-bituminous fuel; but it differs from all others in the place of such admission. I do not admit this fresh air at the bridge, although, by that mode, the

*disappearance* of the smoke is usually the most perfect, because, when so admitted, it operates as a serious check to the draught, and lessens the power of the furnace. Neither is the air admitted at or about the fire-door, because, when so admitted, it has a tendency to be drawn between the fire and the bottom of the boiler, thereby cooling a larger portion of the furnace, and diminishing the economy of the fuel. The necessary supply of fresh air to the interior of the furnace is admitted, in this furnace, at an intermediate position between the fire-door and bridge; or, in fact, it is admitted between the front end and the middle of the fire-grate.

This inlet aperture for the air I make through a hollow or double bearing-bar between the first and second of two or more lengths of fire-bars; and being thus surrounded on all sides by the fire and flame, as in the Argand lamp, it might be called the "Argand fire-grate," or furnace.

The constituent bars of each series of fire-bars are of different thicknesses, the thickest being placed at the back for *slow*, and the thinnest in front for *quick*, or ordinary combustion,—the thin bars having also the widest spaces between them.

In supplying this furnace with bituminous coal, it must be charged thick on the back of the grate, until the coal reaches nearly or quite up to the top of the bridge, gradually sloping forward to the margin of the air-space; while on the thin or front bars only it is fired in the ordinary way.

No complicated apparatus of any kind is required to be attended to, and no additional tools are wanted beyond a "slice" with a blade a foot long, bent flatways, at right-angles, for clearing away obstructions in the air-space. For greater facility in doing this, a modification of the old-fashioned "stoking-bar" is sometimes placed across the ash-pit, exactly under the double bearing-bar, but made in the form of a flat plate, and with a raised ledge to serve as a guide to the tool.* No great degree of care is requisite for preventing smoke in this furnace. It is only necessary to throw the coal boldly in,—principally towards the farther end of the grate,

* My improved *picker-bar* or "stoking-plate," above mentioned, is in the case of a bad draught made to turn on gudgeons, at the sides of the ash-pit, by means of a bell-crank and rod, so as to check or regulate the influx of air through the double-bearing bar, if at any time required.

as a man would fill a cart or a barrow,—and plenty of it, closing the fire-door in as short a time as possible, and the smoke will be found to be no darker than from a common house-fire, provided the air-space be opened occasionally with the slice above mentioned. If the chimney be sufficiently large, which is by far the most important condition, the smoke may thus be made nearly transparent, and, if desirable, can be rendered entirely so by putting a little damp coal on the front part of the fire and taking pains to clear out the air-space after each firing.

The above is a *recipe* for constructing a smokeless steam-engine furnace, than which it is perhaps impossible to imagine a cheaper or simpler arrangement. But it is necessary again to caution those who would adopt it, or *any other plan* of smoke-prevention by hand firing, that the total area of fire-grate should be at the same time increased by 20 or 30 per cent. beyond what is usually considered necessary with the common smoky furnace and ordinary stoking. And besides this, there must be always a surplus of chimney power *at command*, by means of the usual counterbalance weight to the damper, suspended in the stoke-hole within easy reach of the fireman's hand while engaged in charging the furnace. Without those two provisions, especially the first, times will occur, in the case of sudden demands of an engine with a variable load, for steam, when the influx of air must be controlled, otherwise the engine may go slow, or stop, and smoke of greater or less capacity will at such times issue. In the event of the engine going slow from the above or any other *temporary* cause, just after a charge of coal has been put into the furnace, then it is that the fireman finds a resort to the damper most valuable. When the draught is strong, a slight touch of the damper so as to increase the escaping area, will commonly be sufficient to prevent the engine from stopping, or will enable it to recover its speed. In order to estimate the value of a large fire-grate area and surplus draught, it is only necessary to consider what would be the effect, under the same circumstances, with a confined fire-grate and the damper already wide open. There is then, of course, no resource left but stirring the fire, and consequently stirring-up a smoke at the same time.*

* A quick draught is in one respect tantamount to a large fire-grate area, since it equally enables more coal to be burned in a given time, and thus in-

Having shown how easy it is, with a proper arrangement of the furnace bars, to avoid smoke, it will be useful to show how, with improper arrangements, it is also very easy to do a great deal of harm to the boilers, however perfectly the smoke may be consumed or prevented.

That injury to boilers and danger from explosions is to be apprehended from any system of preventing smoke in which a current of *cold* air is directed against the boiler bottom, is no longer a mere opinion, but a fact which cannot be gainsaid. This will appear sufficiently plain to any one who will attentively read the following copy of a report of an examination I made of a case of the kind in Manchester several years ago.

## COPY OF A REPORT ON WILLIAMS'S PATENT SMOKE-BURNING FURNACE.

*To Messrs. Hamnett & Co., Calenderers, Watling Street, Manchester.*

GENTLEMEN:—In accordance with your request, I have carefully examined into the circumstances attending the injury sustained by your steam-engine boiler, during the three-days' trial of Mr. Williams's patent smoke-consuming furnace, and have to report thereon as follows:—

Some of the plates in the boiler bottom behind the bridge appear to have been exposed to a considerable degree of expansion and contraction alternately, arising from frequent alternations of temperature, by which means the rivets have been dragged successively in opposite directions, until they have become loosened in the rivet-holes, and the boiler has become leaky.*

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creases the power of the boiler in generating steam. A quick draught, however, has this further advantage,—that inasmuch as the temperature of the furnace is higher when the same quantity of heat is generated in a small space than what it will be when generated in a large space, the heat is transmitted much more rapidly to the water of the boiler in the case of the strong draught, by reason of the higher temperature in that case obtaining. As, therefore, there is more heat transmitted in the region of the furnace in the case of the strong draught, there will be less remaining to be transmitted in the region of the flues. In other words, the flues will have less work to do, and they may either be made shorter, or the heat will be more thoroughly absorbed.—J. B.

* *See* illustrations of similar effects in figures 97 and 99, Chap. XXVII.

One plate is also what is usually called "burnt out," which is what generally happens when one side of an iron plate is frequently and suddenly heated and cooled, while the other side, from its contact with the water in the boiler, is kept at a moderately uniform temperature. In this case, also, owing to the necessarily *laminated* structure of wrought iron, combined with the heating and cooling process above described, "a blister" has arisen in one of the plates, and this blister has been the immediate cause of the giving way of the boiler, by so far weakening it as to allow the pressure of the steam and water to force down the plate in that particular place.

The main cause of the above results is clearly to be traced to the imperfect construction of the furnace, inasmuch as the passage for the admission of fresh air to the flame behind the bridge is unprovided with a valve or other means of regulating the quantity of air so admitted, or the time of its admission, *within the reach of the engineer* whilst engaged in firing the boiler.

To enable me to explain this point more fully to your satisfaction, I may state that this mode of preventing, or (as it is most commonly called) "*burning*" the smoke, by admitting atmospheric air at or behind the bridge of the furnace, has been long known, and frequently practised in Manchester since it was first generally introduced here by Mr. John Wakefield more than twenty years ago. This gentleman also practised the method of *diffusing* the air through several small apertures inside the furnace chamber, in the same manner as Mr. Williams. But in all Mr. Wakefield's furnaces, as well as those of Mr. Parkes, that I ever saw, the passage through which the air was allowed to communicate with those apertures was supplied with a regulating valve for the purpose of admitting the proper quantity of air, suitable to the varying state of the fire, or to shut it off at the discretion of the engineer or fireman. And the uniform practice of all operative engineers has always been, when no flame was passing from the fire, and consequently no smoke being made, to shut the air off entirely.

In your case, however, the furnace is so arranged that a constant stream of cold air is uniformly rushing into the main-furnace chamber or flame-bed of the boiler *at all times*, and whether there is a flame passing over the bridge or not.*

* I am aware that the production of the invisible carbonic-oxide gas, from a thick coked fire, may sometimes create a demand for air when no black smoke

The certain and inevitable consequences of this state of things are, that every time the fresh coal is thrown on the fire, and a flame is produced sufficient to reach *through* the throat of the furnace, the current of fresh air passing directly into [or against] the flame from below, drives the latter right up against the boiler bottom in the manner of a blow-pipe, causing it to impinge with peculiar intensity against that portion of the boiler bottom immediately exposed in the direction of the blast. On the other hand, as soon as the fire on the grate has burned bright, *and the flame does not extend over the bridge,* the COLD air striking against the same part of the boiler bottom, which had just before been so unduly *expanded* by intense heat, a *sudden contraction* of the metal necessarily ensues, besides a great waste of fuel, and difficulty in keeping up the steam.

I have long paid great attention to the operation of smoke-burning furnaces generally, and more particularly to those constructed on the principle so imperfectly attempted by Mr. Williams, that is, by supplying to the carbonaceous products evolved, their full saturating equivalents of oxygen for effecting the most perfectly attainable combustion of their elements, and thereby preventing smoke, but which can only be safely effected by carefully *regulating* the admission of air to the flame, for which, in Mr. Williams's plan, there is no provision made whatever. I have no hesitation in stating that the result of my experience is a confirmed opinion against the economy of the process; being convinced, that, in ordinary circumstances, there is more fuel wasted by the admission of cold air to the boiler bottom, than is saved by the most perfect

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is passing. But I contend that such air should be supplied through the grate, and not behind the bridge, unless carefully regulated.

Hypercriticism might contend that, instead of a "stream of cold air," it would have been more correct to say *streams* of cold air, inasmuch as the air was supplied through a perforated plate between two bridges, which did not form, strictly speaking, the split or *double bridge* of Parkes, being much wider apart. These numerous streams, however, united and became one stream after passing through the meshes of the "Patent Riddle," which riddle grating or perforated plate formed the special claim of the patent, and could be of no earthly use, unless indeed it had been used for heating the air. That purpose, however, was especially *disclaimed* in the patent, and the air, in this particular case, was brought in a separate channel at a distance from the boiler intentionally that it might be *cold*, and that all access to it by the engineer might be cut off.

consumption of the smoke. This conviction has been forced upon me by a careful and unprejudiced examination of a great many steam-engine furnaces erected both by myself and others, including several constructed by Mr. Williams himself.

I may take the liberty of concluding this report with a caution which I have been in the habit of giving verbally to all those who have occasionally consulted me on this subject for some years past. It is that I have reason to believe that many extensively fatal explosions of steam-boilers, not otherwise satisfactorily accounted for, have arisen from similar causes to those detailed above, namely, frequent and sudden alterations of temperature at the lower part of the boiler, inducing a tendency to burst downwards, of which instances are constantly occurring. In fact, in the case of your own boiler, the minor explosion it has experienced may be considered in the light of a very narrow escape, for if the blistered plate had been of rather a better quality of iron, so as to have held out a few days longer, or until one or two of the adjoining already injured plates had become nearly as weak as itself, in all probability they would have given way simultaneously, and produced an extensive explosion, the effect of which is usually, by reaction, to force the boiler upwards, sometimes to a considerable height through the supervening buildings, in a way that has too frequently created an enormous destruction of life and property. ROBERT ARMSTRONG.

The reason for giving, perhaps, undue prominence to the above letter or report, is that it was not *orginally* published by me,—that is, if printing and giving away a large number of copies may be considered as such,—but by Mr. Joseph Williams, of Liverpool, then (in 1841), as now, well known as the proprietor of the patent smoke-burning furnace of his brother-in-law Mr. Kurtz, a scientific chemist of considerable eminence. The letter itself was properly a private business one, which, with other evidence, was, after revisal by me, put into the hands of the solicitor of the firm of Hamnett & Co. for legal purposes. Although not then called on to justify the publication, I did not object to it, because Mr. *Joseph* Williams represented to me the injury his character and that of his patent—which was for the use of *hot* air—might sustain in being confounded with those of Mr. *Charles Wye* Williams, whose

patent was for the use of *cold* air, owing to both persons having the same surname.* Consequently many thousand copies of the report were printed and circulated by Mr. *Joseph*, setting forth the distinctive appellations of himself and Mr. *Charles Wye* at full length. This procedure was also followed by Mr. John Chanter of London, the proprietor of numerous smoke patents, publishing the same thing. The object of both those gentlemen was probably the same, that of demolishing the business of a rival patentee, which, there is no doubt, they did most effectually; raising, at the same time, some rather undignified discussions in the public press on their various claims to notoriety in saving thirty, forty, and fifty per cent. in fuel. In those discussions, except in self-defence, I took no part, having no pecuniary interest in any smoke patent, nor any sympathy whatever with any of the combatants.

So effectually had all public interest died out in the above discussion, which was supposed, as usual, by many to be settled in favor of those who care to have the last word, that I did not think it necessary to allude to the subject in my "Rudimentary Treatise on Steam-Boilers," in 1851. The subject however, has been revived by the Society of Arts awarding one of its prize-medals for an essay on smoke-prevention, among others, to Mr. C. Wye Williams, who must have convinced the society that, "though beaten, he can argue still." In this prize-essay Mr. Williams has endeavored to revenge his former discomfiture by an onslaught on the whole of the present generation of patent smoke-burners which I do not notice, but for the unfair use he makes of the above report,—*misquoting*, garbling, and perverting it in every possible way.† Hence the obligation I am under in giving my report at full length as above.

Considering that, although I stand sufficiently absolved from the necessity of noticing Mr. Williams any further, there are one or two others whose practical abilities as engineers the public hold

* It is remarkable that four different persons of the name of *Williams*, Irish, English, Scotch, and, I believe, Welsh, were the holders of smoke-patents during the same year,—the first and second of whom only we now refer to.

† See his letter on the smoke nuisance in the Engineer newspaper, for May 30th, 1856.

in high respect, who have been led astray in this matter of smoke-prevention, but who can have no interest or desire, except to be set right as to facts. I think it proper here to narrate the results of some experiments I witnessed upon smoke-burning in 1843, with the view of illustrating some of the points then under controversy. This information is afforded in the following memorandum:

### ACCOUNT OF EXPERIMENTS CONDUCTED AT THE COTTON FACTORY OF THOMAS HOULDSWORTH, ESQ., M.P., IN MANCHESTER, IN 1843, IN ORDER TO DECIDE ON THE ECONOMY OF SMOKE-PREVENTION.

It will be remembered that a select committee of the House of Commons was appointed to investigate the smoke-nuisance question in 1843, the results of which investigation were published in a blue book about the end of that year; and on the evidence contained in that and other reports, Parliament afterwards proceeded to pass several new laws on the subject—a very proper thing in itself, if founded upon truth instead of the most erroneous statements to the effect that manufacturers would be greatly benefited by the measure in the saving of fuel thereby insured.

Among other questionable evidence, by much less reputable parties, published in this blue book, was a statement by Mr. H. Houldsworth, supported by a long array of tables and diagrams, asserting that, "by an admission of air to the extent required to prevent smoke," into the "body" of a steam-boiler furnace, "much additional heat is produced, more steam raised from the same weight of coals, and more water evaporated in the same time." Particulars of four experiments are detailed in order to show that a gain of thirty-five and thirty-six per cent. was "made by admitting air partly at the door, and partly at the bridge, through one of Mr. C. W. Williams's diffusion-boxes" (or patent perforated plates). In the appendix to the report it is stated that, "in each experiment 1840 lbs. of Knowles's Clifton coals were burnt; a free-burning kind, much used in Manchester. The boiler was one of Boulton and Watt's, twenty-four horse power, wagon-shape."

The following extract is from Table B., Appendix No. 5, page 201, referred to in the evidence of Henry Houldsworth, Esq. *Vide* Q. 1100, page 102, July 27th, 1843.

| AIR. | Effect per minute. | | Water evaporated by | | Economic Effect |
|---|---|---|---|---|---|
| | Coals burnt. | Water evaporated. | 1840 lb. of Coal. | 1 lb. Coal. | |
| | lbs. | galls. | galls. | lbs. | |
| No air... ... ... ... | 4·64 | 2·5 | 992 | 5·41 | 106 |
| 43 square inch constant aperture ... ... ... | 4·68 | 3·21 | 1,263 | 6·85 | 135 |
| Air, regulated partly by the eye and partly by a scale, varying in some degree with the action of combustion ... ... | 4·43 | 3·09 | 1,280 | 6·94 | 134 |
| No air... ... ... ... | 4·43 | 2·3 | 942 | 5·12 | 100 |

The first effect of Mr. Houldsworth's published statement was the industrious propagation by some of the Manchester and Liverpool Journals, of the fallacious inference that 35 or 36 per cent. in fuel was to be saved by smoke-burning instead of 25 per cent. only, supposing his experimental data to be right. That, however, was denied by many manufacturers, and the result was a request to Mr. Houldsworth to repeat any of his experiments likely to show them so very desirable a result. This, after some preparation, was agreed to, and I was appointed by the firm of George Clarke and Co. as their consulting engineer to witness the experiment, and was also retained for the same purpose by other manufacturers who felt great interest in the subject.

These trial experiments took place by appointment on the 19th and 20th December, 1843, and the following summary of the results, after undergoing the revision of Mr. Billington, who superintended the experiments on the part of Mr. Houldsworth, and a written acknowledgment of the latter gentleman to their correctness, was transmitted by me to Messrs. Clark and Co., and other firms interested in the matter, also to Mr. Wm. Fairbairn and other engineers, who appeared to be so.

SUMMARY.

*Results of the experimental trial of the comparative economy of Mr. C. W. Williams's patent system of smoke-prevention and the ordinary plan.*

"The exact results of the smoke-burning experiments made at Mr. Thomas Houldsworth's works, on the 19th and 20th of Dec., 1843, are as follows:

"At one boiler having Williams's Patent Argand Furnace attached—that is with a permanent aperture admitting a *continuous* current of air through a perforated plate or 'diffusion-box' behind the bridge,—by the consumption of 1150 lbs. of coals, the evaporation was 569½ gallons of water in 5 hours 22 minutes;—and on the following day, namely, the 20th of December, 1843, with *the same boiler*, the *same quantity of coals* from the *same heap*, and every thing exactly in the same state as before, except that the aperture for admitting air at the bridge *was kept carefully closed* the whole time, and the holes in the fire-door plugged up, the evaporation was 713½ gallons in 5 hours and 20 minutes. The experiments commencing each day at the same hour."

Rate of evaporation per lb. of coal is accordingly:—

With air admitted 4·95 lb. water to 1 lb. Coal.
Without ditto . . 6·2 lb. " 1 lb. "

Difference 1·25 lb. or 25 per cent. more steam in favor of the ordinary plan and *against* smoke-prevention, instead of 35 per cent. by *parliamentary evidence* the contrary way!

After so signal a failure as the above, what must we think of a statement which the publisher has been influenced by Mr. Williams to insert *twice over* in an unauthorized "Appendix" to a surreptitious edition, miscalled by him the *third* of my "Rudimentary Treatise" to the effect that Mr. Houldsworth had, "as a result of his reading Mr. C. W. Williams's book on combustion," reduced his consumption of coal from 20 to 17 cwt. per hour? My answer to this is, that previous to his adopting Williams's system, he was using at the rate of 7¾ lb. of coal per indicated horse-power per hour,—full 20 per cent. more than the average rate of other manufacturers at that time, which left room for saving even by the adoption of a bad plan.

Mr. Houldsworth's consumption was not therefore the "ordinary," but an extraordinary and extravagant consumption of coal. This is amply authenticated by various duty report papers of Manchester engines now before me; a fact which constitutes him a very weak authority on the subject, the only nominal (engineering) support he occasionally had in Manchester to the contrary, notwithstanding.

Many other proofs abound, utterly condemnatory of the perfect combustion notion, in its application to steam-engines; but as that system is now perfectly defunct, if it ever was alive, except on paper, I shall here conclude with some observations printed several years ago on "perfect" and "imperfect" combustion, for the use of those who require a more rational theory on the subject, and which I now take the liberty of entitling

### A THEORY OF THE BEST POSSIBLE COMBUSTION IN STEAM-ENGINE FURNACES.

It is true that smoke is a result of imperfect combustion, but it is also true that combustion may be still more imperfect without smoke, and be attended with a much greater waste of fuel. In a steam-engine furnace, there never was, and never can be "Perfect Combustion," even in theory, much less in practice. In the nearest *apparent* approach thereto, when no *visible smoke* escapes from the chimney, there always arises from a fire of tolerable thickness a certain quantity of unconsumed inflammable gas, chiefly carbonic-oxide, whilst at the same time, a very large proportion (according to experiments by Peter Ewart and John Dalton about *one-half*) of the gaseous products passing off by the chimney consist of atmospheric air *unchanged*, that is, containing its full proportion, about one-fifth of oxygen. Now, since it is impossible to increase the supply of oxygen, which, by combining with the fuel in the furnace, is alone the cause of all the heat produced, without at the same time increasing the supply of the other component of the atmosphere, consisting of *four-fifths* of it, namely, the nitrogen; and allowing, as above, one-half only of the oxygen to be available, it follows that about nine-tenths of the atmospheric air admitted into the furnace, and heated to a temperature of about seven hundred degrees, is carried off by the chimney for no purpose what-

ever, except to enable the remaining one-tenth to support the combustion of the fuel.

An exception may be taken to this on the ground that some part of this waste heat may be recovered by an extended heating-surface of the boiler; that, however, is limited in practice by other circumstances, and does not affect the above conclusion as regards the furnace considered by itself.

Whether heat is a material substance or not, which is immaterial to this question, it is quite certain that in its production from the burning of common bituminous coal, the main elements concerned are carbon, hydrogen, and oxygen, and that the *complete conversion* of these three substances into carbonic acid and water without waste, is the only common-sense idea that can be conceived of *complete* or "perfect combustion." And, if we would have a continued supply of oxygen without its accompanying nitrogen, such combustion might be possible; but as we can only have these two elements *mixed* as we find them in the atmosphere, and one of them having to be separated from the other, as they pass through the furnace, whilst so large a portion as nine-tenths of the whole is of no use in the process, the case is considerably altered.

Take, for instance, any given ordinary furnace, and supposing it to be in operation and supplied with fuel at a given *uniform rate*, if we then suppose the air supporting the combustion to be supplied at a *uniformly increasing rate*, it is certain that a maximum point, in the relative proportions of the air and fuel, must be somewhere arrived at, where the expenditure of heat on the liberated nitrogen and other *incombustible products* escaping by the chimney must counterbalance the heat created by the consumption of that portion of any combustible gas or smoke that would otherwise pass off unconsumed in the same way,—the former increasing as the latter diminishes, and *vice versa*.

This maximum point of BEST POSSIBLE COMBUSTION once attained, we can neither pass nor fall short of it without diminishing the temperature and eventually stopping the process. Or, in other words, the oxygen, which alone supports the combustion, must not only create as much heat as is sufficient for heating itself, but also as much as is required to heat up to the same degree all the air or gases with which it is in contact: otherwise the combustion will not go on at the same rate, and consequently a lessened supply of

steam to the engine results, and less *power*, the only true measure of heat, is produced.

The natural conclusion from the above theory—which is also in strict accordance with all successful experience—is, that the most economical method of firing a steam-engine boiler, from which a constant quantity of steam is required, must be by a regularly uniform supply of fuel to the furnace, and a similarly regular supply of air through the fire-grate, "and nowhere else," with a uniform though moderate emission of smoke, visible or invisible, from the chimney: *visible* within certain limits of density of shade, as the combustion is more or less imperfect,—being least imperfect when the combustion is quicker and the resulting products contain the largest proportion of carbonic acid gas and steam, holding in suspension a thin, gray coloring of carbon or soot, which constitutes ordinary smoke; *invisible* when the combustion is slower and more imperfect, allowing the carbonic acid first formed to be replaced in the escaping products by a large quantity of carbon in the form of carbonic oxide gas, thereby wasting, at least theoretically, nearly half the available carbon of the coal.

## CHAPTER XXVI.

### REMARKS ON SMOKE-BURNING, BY JOHN BOURNE, ESQ.

[The following remarks form a portion of a review of Mr. Charles Wye Williams's book on "The Combustion of Coal and the Prevention of Smoke, Chemically and Practically Considered," which appeared in the "Artizan" for February, 1843.]

THE smoke evolved by every species of bituminous coal, when burned in common furnaces, must necessarily detract considerably from the caloric efficacy of the fire, both on account of the direct loss of a portion of the combustible, which passes off in the form of smoke and is dissipated in the atmosphere, as well as from the loss of the heat requisite to convert the hydrocarbons so dissipated into the gaseous form. Numerous attempts have been made to obviate or diminish these sources of waste, by admitting into the flue or furnace a stream of air to accomplish the combustion of the inflammable parts of the smoke. But the difficulty of apportioning the quantity of air admitted to the varying wants of the fire, has been found an insuperable objection in the case of ordinary furnaces: whilst the refrigeratory effect of the excess of air it is necessary to admit in order to bring the atoms of the combustible and the supporter within the range of combining attraction, goes far to neutralize the increased heating-power consequent on their combination. In experiments upon smoke-burning furnaces, conducted with great care and skill, possibly some little saving may have been repeatedly realized. But with the measure of care and skill which furnaces can obtain in the ordinary routine of practical operation, smoke-burning has invariably been productive of a diminished efficiency, or an increased consumption.

All this Mr. Williams acknowledges; but maintains that his is not a smoke-burning, but a smoke-preventing furnace. Smoke, he admits, cannot be burned advantageously. But it is not smoke,

he says, but gas, that he attempts to consume. The difference is certainly conceivable, and not unimportant; yet, on looking at the construction of Mr. Williams's furnace, we find that the furnace proper differs in no respect from common furnaces; and the aeriform matter which passes through the furnace-throat must therefore, necessarily, be of the usual description. The whole of Mr. Williams's plan, indeed, consists in letting air into the flue by a multitude of holes. But the substance to which the air is admitted is identical with that in furnaces of the ordinary kind; and his furnace is, therefore, just as much a smoke-generating furnace as any furnace whatever. The difference between smoke and gas is simply this: One is the product of imperfect or incomplete combustion, whilst the other is not the product of combustion at all, but of volatilization merely. And, as combustion is carried on in this gentleman's furnace, the substances flowing past the diffusion-orifices, which are the product of that combustion, cannot be coal-gas by any possibility. The question really at issue, is not whether it is beneficial to admit air to gas in one hole or in many holes, but whether, in the case of this furnace, it is gas at all to which the air is admitted. To pretend that smoke can be turned into gas by letting in air upon it by one hundred holes, instead of by one or two, is just as preposterous as to maintain that the plant which, when watered with a common watering-pot, is a lily, will be turned into a thistle if watered with a jug. In spite, then, of all the indignation Mr. Williams has heaped upon "smoke-burning pretenders," it is, in our eyes, undeniable that he is himself one of the genus he so loudly condemns; and as we participate to a certain extent in his disapproval of smoke-burning expedients, we are compelled to surrender him to his own reprobation.

The ineffectual and injurious character of Mr. Williams's arrangements, are, we think, very ably pointed out in a report of Mr. Armstrong's, addressed to a respectable manufacturing firm in Manchester, and inserted at p. 274 of the present work.

In answer to this statement, Mr. Williams contends that when there is no smoke to be burned, there is carbonic oxide, and that therefore a rush of cold air through the diffusion orifices at any time is impossible. But if the furnace be made to produce carbonic oxide in considerable quantity at all, so as to combine with the oxygen when there is no smoke, this carbonic oxide must pass

off unconsumed where there is smoke, provided the smoke be consumed, and a great waste of fuel must thereby be occasioned. In the case of ordinary furnaces, it appears impossible indeed for Mr. Williams to extricate himself from this dilemma. He must either have a current of cold air rushing at times through the diffusion orifices, cooling and injuring the boiler, or large quantities of carbonic oxide continually escaping into the chimney, so as to occasion a material waste of fuel. On the whole, it appears to us that although this project may be capable of affording some satisfaction so long as it meets with the care due to a novel and nurseling project,—as, indeed, a host of previous schemes have repeatedly done,—yet that in the aggregate of ordinary working it will approve itself troublesome, expensive, and pernicious.

Of Mr. Williams's book, our verdict, we fear, must be as unfavorable as of his invention; yet it has received high praise in various quarters; and although its admirers are not the best sort of admirers, we doubt not their panegyric has been accepted by Mr. Williams as good sterling praise, and will probably render distasteful any more discriminating analysis. Indeed, the expectations of any author who has once tasted of popular applause, are by no means easily satisfied. Upon his first appearance before the tribunal of public opinion, he will generally be content if he escape without censure; but his expectations rise with his success, and the judgment he would at first have accepted with joy and gratitude, he will speedily come to look upon as prejudiced and disparaging. Upon any person, indeed, prominently before the public, a word of disapprobation falls with prodigiously increased weight: so long as he remains in obscurity, reproof is unattended with disgrace because it is necessarily unwitnessed, but the crowd he brings around him by his triumph, if it adds to the brilliancy of success, fearfully aggravates the penalties of failure. Every voice which swelled the measure of his fame will add to the ignominy of his degradation; and a measure of praise which would have exceeded the hopes of his earlier ambition will now only suggest humiliating ideas of his unfitness for the position he has so incautiously usurped, and the derision and disappointment his incapacity has excited.

An inquiry into the phenomena attendant upon the combustion of coal divides itself into two parts. First, The determination of the chemical constitution of the coal; and, Second, The determina-

tion of the quantity of air requisite for the combustion of its constituents. Mr. Williams has gone into both of these subjects at considerable length. He has given us a compilation of authorities showing what the chemical composition of different species of coal is, and has favored us with several chapters and a multitude of diagrams to point out that carbon and hydrogen combine with oxygen in definite proportions. In the whole of these most ingeniously constructed chapters, there is not a single remark of the least worth or moment; and in the whole length and breadth of the book there is nothing new, except its errors and the magisterial solemnity with which the most trite and insignificant truths are reproduced and paraded. Indeed, Mr. Williams seems very fond of burning his gas in the blaze of noon-day. He devotes pages to prove self-evident propositions, and takes infinite pains to convince sceptics of things nobody ever thinks of doubting. He continually speaks of atoms as if he himself had found them out, and as if an introduction to so difficult a theme inspired extraordinary trepidation; as in page 40, for example where he encouragingly tells us "*not to feel alarmed* at this introduction to elementary atoms and chemical equivalents." In pages 27, *et seq.*, the discovery is announced to us, that when fresh coal is thrown upon a fire, the fire is afterwards not quite so hot as before; in pages 28 and 29, we are assured that heat is necessary to expel gas from coals; in page 35, that a combustible as well as a supporter are indispensable to combustion; and in page 37, that the combustion of gas is accomplished, "not by its combination with the air, as is the vulgar and dangerous notion, but with the oxygen of the air—the supporter of flame—the heat-giving constituent of the air." In page 91, we are told, "Without sufficient time, nothing short of a miracle could satisfy the required extent of diffusion. Nature, however, does not operate by miracles, but by defined laws and progressive means;" and in page 129, we are assured that combustion cannot take place without air; "that providing heat is not providing air, neither is decomposition combustion." In page 11, we are told that Sir Humphrey Davy was an eminent man; in page 20, that Dr. Faraday is the first electrician of the day; and in page 41, that John Dalton is a writer of merit. At page 70 commences a chapter of 30 pages for the purpose of pointing out that as it is oxygen which supports the combustion in a furnace, the air sup-

plied to the furnace must not have been deprived of its oxygen previously, else it will not do:—for thus wisely and thus learnedly argues this philosopher, "If oxygen be not present in the air, how can it otherwise be obtained? How can we effect a union with a thing which is not?"

In extenuation of the marvellous superficiality of this gentleman's treatise, it may, perhaps, be urged that he wrote not for scientific, but for practical men. This argument might, perhaps, have some weight if by practical men were meant our working boiler-smiths and bricklayers, who for the most part are supposed to know as much of chemistry as of the Œlic reduplication; yet, even in this case, we do not altogether see how those persons should be induced to read this book more readily than some of the numerous chemical works to which they already have access. Mr. Williams, however, informs us that he does not address himself to so unpromising an auditory, but to those by whom engineering works are directed and designed. 'Are then our bricklayers or boiler-makers to become chemists? No. But those who direct—those who assume the charge of teaching them to construct the numerous descriptions of furnaces with which this country abounds, —should be masters of the leading principles on which their art is based, and the success of their operation depends,' of which it would appear they at present know nothing. Thus in page 2, Mr. Williams informs us, that even the most experienced engineers know very little about the boiler—in page 3, that in the construction of boilers engineers are without any fixed principles to guide them—in page 4, that he has watched the efforts of engineers to arrive at some degree of certainty, that he has perceived the absence of any intelligible or well-founded principle in the boiler—in page 5, that instead of improvement there has been latterly retrogression, and that well-established houses even yet know very little of the principles of perfect combustion, or of the economy of fuel. From these and numerous other passages, which might be cited, it would appear to be this gentleman's doctrine that engineers are a very ignorant and stupid race of persons; that though living in England in the nineteenth century they are unacquainted with the simplest and most familiar truths of chemistry; and while possessing the reputation of producing those miracles of ingenuity which carry their fame to the verge of civilization, that they exist in a

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state of mental stupor which the most besotted Turk could scarcely hope to emulate. A person, indeed, who derived his only information on this subject from Mr. Charles Wye Williams, might imagine our mechanics to be the descendants of some barbarian horde on whom a hereditary curse rested, dooming them to an eternal degradation; who remained rude and untutored even in the centre of civilization, and whom the flame of science could neither melt nor quicken, nor the lessons of experience instruct. It is not astonishing, therefore, that Mr. Williams should speak with much confidence and coolness of the absurdities of the practice of our engineers, which in pages 34, 72, 73, 74, 127, and, indeed, in almost every page throughout the volume, he most industriously exposes. He takes especial care to make manifest the shallowness of Tredgold, and the erroneous notions of Watt, which he of course contrasts with his own higher skill and superior illumination, and finding himself unable to refute what they *do* say, wisely confines his refutation to what they *do not* say. In page 134, he states, 'the erroneous view of the combustion of the gases began with Watt;' but after handling poor Watt very severely for his manifold shortcomings, he kindly winds up in the following patronizing strain: 'But let justice, however, be done to Watt. It is not his fault that the errors he committed should continue to be repeated,' which our present engineers are, it appears, wrong-headed enough to do. The following epithets are therefore unsparingly applied to the practice of those obdurate persons: 'erroneous,' 'lamentably erroneous,' 'neglect of chemistry,' 'notable instance of neglect of chemistry,' 'abortive attempts,' 'great practical and chemical error,' 'palpable oversights,' 'unsound principles,' 'chemical blunder,' 'utterly at variance with chemical propriety,' and a host of other equally decorous and appropriate expressions. The secret of all this we suppose is, that Mr. Williams plumes himself not a little upon the smattering of chemistry he appears to have acquired, and in the simplicity of his heart imagines that because our leading engineers do not think it consistent with their dignity to become lecturing itinerants, or to be eternally flashing their attainments in the eyes of ignorant spectators, they know nothing of the most familiar scientific truths, and pay no regard to them in their practice. If Mr. Williams could only see himself as he is seen by others,—if he could only perceive the ridicule he draws upon him-

self, by harping everlastingly about chemical principles, and chemical blunders—and which we can assure him raises the secret laughter of even the most favorably affected,—he would, we are sure, gladly retire into the obscurity for which Providence manifestly designed him, and leave the contention for distinction to those who have something better to offer as credential than a flood of scientific jargon, or the pitiful pedantry of a boiling empiric.

J. B.

# CHAPTER XXVII.

## EXPLOSIONS: AN INVESTIGATION INTO SOME OF THE CAUSES PRODUCING THEM, AND INTO THE DETERIORATION OF BOILERS GENERALLY.

How to obtain sufficient strength to resist the disruption of the materials of which boilers are composed is one of the principal considerations usually advanced in investigations respecting boiler explosions. Setting this topic aside, for the present, and dismissing the discussion of theories of explosions, we shall endeavor to collect here the practical results of the most uniform experience relative to the explosions of boilers which are imputable to common causes.

We shall also examine such experiments as illustrate the proper forms and dimensions of boilers in common use, and shall recapitulate the principal sources of weakness arising from ordinary tear and wear, from improper management and from other usual incidents in practice.

### AMERICAN EXPERIMENTS ON EXPLOSIONS.

The most authentic illustrations of the inferior limit of the thickness of metal proper for boilers, are two experimental explosions purposely produced in the course of a series of very important investigations, undertaken by a committe of the Franklin Institute of the State of Pennsylvania, at the request of the American House of Representatives, for whom the report of these experiments was first published in America in 1836.

The immediate object of the two experiments in question was "to observe accurately *the sort of bursting* produced by a gradual increase of pressure *within* cylinders of iron and copper." This course was pursued because it had been assumed by many, and indeed the opinion was very generally entertained in this country

as well as in America, that ruptures produced in *copper* boilers would not bear the character of explosions, but that a mere *rending* would take place, giving an easy escape to the contents. In pursuance of this investigation, two cylinders were prepared of such a size as it was thought would make a small thickness of material illustrate the question, "by rending at a pressure which was easily attainable."

In this respect the committee would have found less difficulty if they had made the boilers of a larger diameter; for it appears they really had considerable trouble in causing the boilers to explode at all. However, they did at last succeed, and the results afforded a direct answer to the question between iron and copper, proving the entire want of foundation for the opinion which asserted the superior safety of the latter. Collaterally, also, those results afford good grounds for the first step of a general inquiry into the causes of the explosions of boilers.

### EXPERIMENTAL EXPLOSION.

The iron boiler used in this experimental explosion was cylindrical, ten inches long by eight and a half inches diameter, and one-fiftieth of an inch thick, with ends one-twentieth of an inch thick, to which the curved portion was fixed by rivets, nearly touching each other. A single opening in one of the ends of the boiler admitted the water, which was then furnished with a screw, also with a tube and piston, connected with a small spring-weighing machine.

"Upon the cylinder of this machine a ring was placed, which was movable along the cylinder by a slight pressure; this ring was forced towards the end of the cylinder nearest to the boiler head,

as the spring was bent, and remaining in its place as the spring relaxed, served to register the maximum pressure to which the piston had been exposed previous to observing it."*

The small iron boiler thus prepared was half filled with water, and placed on a charcoal fire, and the steam got up; but owing to a leak in the riveting, the steam escaped so fast, that the operators were unable to burst the boiler on the first trial. The boiler was, however, replenished with water, and set lower in the fire, which was again urged, when, at last, with some difficulty, an explosion was produced.

So little dependence can, in general, be placed on the relations made by witnesses of accidental explosions, and so rarely have explosions been intentionally made for the purpose of illustrating this question, that, for the sake of accuracy in preserving all reliable facts, the different members of the committee simultaneously addressed their attention to the different circumstances which had to be observed at the time the explosion took place.

"Part of the committee were engaged in observing the progress of the experiment at this moment. The fire was near the middle line of the boiler,† burning not strongly near that line, but very rapidly below the boiler; the steam issued freely through the leak before alluded to, and the whistling sound which it produced, and *which had increased gradually in strength,* as the experiment progressed seemed constant. The length of time during which the steam had escaped showed the water to be low, and induced the supposition that a second time the object would fail; when an explosion occurred."

### THE CROSS-LANE, MANCHESTER, EXPLOSION.

After recounting the incidents of this case of artificial explosion, I shall now proceed to describe some of the cases of real explosion which have occurred in practice. One of these cases is that of an explosion which took place several years ago, by the bursting of a small cylindrical boiler, of about three feet in dia-

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* See the original Report, page 66.

† As the boiler rested horizontally in the fire, and was half filled with water, this middle line and the water surface would nearly coincide.

meter, used for the purpose of working a six-horse non-condensing engine, at a pressure of 60 lbs. per square inch. It had *two safety-valves*, each of about a square inch area, and both were stated to be in full action at the time the explosion took place, having commenced blowing off steam a few minutes before.

The result of this explosion was, that the wrought-iron end of the boiler next to the furnace was torn away, principally by splitting the angle-iron, which was barely three-eighths of an inch thick, and thrown more than twenty yards off, carrying the fireman six or seven yards of that distance, who, together with another man, was killed on the spot. The body of the boiler was driven in a contrary direction, through both the external walls of the engine-house, one nine and the other fourteen inches thick, at the same time carrying away the steam-engine itself several yards into a field, at the other side of the building.*

### THE JERSEY STREET, MANCHESTER, EXPLOSION.

Another apparently similar kind of explosion to that just described, took place in October, 1841, at the machine manufactory of Messrs. Elce and Cottam, in Jersey Street, Manchester. This boiler, like the previous one, was employed to drive a six-horse high-pressure, or non-condensing engine, having an eight-inch cylinder and a two feet stroke, working usually at a pressure of from 26 to 36 lbs. per square inch. The safety-valve, which was of the common kind, with a *packed spindle and stuffing-box*, was adjusted by means of a Salter's spring-gauge, to blow off at 40 lbs., beyond which pressure it could not be screwed down.

This boiler was a cylinder of nine feet six inches in length, with flat ends, three feet ten and a-half inches diameter. It was made of good iron, three-eighths of an inch thick all through, and had been some few years at work. The two ends, or as the Americans call them, "heads" of the boiler, were braced to each other by one

* This explosion took place in October, 1832, at a saw-mill in Cross-lane, Manchester, belonging to Mr. George Jones. The engine and boiler were both quite new, having only worked a few days, although at the time of the explosion the engine had been stopped for a few minutes for the purpose of adjusting a strap on the machinery.

longitudinal wrought-iron stay-bar through the centre, attached at each end by a wrought-iron strap and cotter. It was the giving way of this strap, against which the cotter was driven, through a slot in the stay-bar, in the usual manner adopted for low-pressure wagon-boilers, which was the *immediate* cause of the explosion. The strength of the iron, however, at the place of fracture, when examined by good judges, was pronounced to have been capable of resisting a pressure on the end of the boiler of at least 100 lbs. to the square inch.

## STICKING OF SAFETY-VALVES.

That the support above mentioned should have given way when the safety-valve was free to open at 40 lbs. per square inch, or less than one-half the pressure that it was proved to be thoroughly able to sustain, is one of the anomalies we are so frequently meeting with in these investigations. I would here call attention to this point; because nothing would be easier than to make short work of such cases, by saying that the safety-valve must either have "*stuck* or *jammed*," or otherwise must have had additional weight put upon it at the time. This, in fact, was the conclusion come to by three practical engineers of the highest eminence, who agreed to deliver to the coroner's jury a joint report on this case.

This *sticking* and *jamming* of safety-valves, is, in any case whatever, so extremely improbable, that a resort to this explanation, without actual proof of its existence, is much to be reprehended. In this particular case, it is true the safety-valve was found broken off and blown to a considerable distance, having its spindle somewhat bent, and it had been wrapped with a certainly improper packing of hemp; but even if the bending of the spindle had been done previously to the explosion (which was in the highest degree improbable), the "sticking" thereby created in the packing, could not have added many pounds per square inch, to the resistance offered to the free escape of the steam.*

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*NOTE BY AN EMINENT GOVERNMENT ENGINEER.

"I fear that it is difficult to say what amount of force is sufficient to raise a safety-valve whose spindle is bent, and therefore I would suggest that 'a

Not a much better stalking-horse than this universal sticking-point is the criminal overloading, or "*making-fast*" the safety-valve. Any imputations of this kind without the most clear and positive evidence, both direct and circumstantial, is simply begging the whole question. There is very rarely, except in the case of locomotives, any inducement to do any thing of the kind, but very frequently the contrary, as was very likely to be in the case before us. For the engine had not started, and from the proved careful habits of the engineman who was killed by the explosion, it is much more probable that he *opened* or eased the safety-valve, by removing all or part of the load upon it, and my firm conviction was, at the time, that he did so, and that the boiler blew up on the instant, or in a few seconds afterwards.

## DEFICIENCY OF WATER.

In the Jersey-street boiler, as well as in that at Cross-lane, might be seen distinct traces of the water having been too low. There were certain marks left by the sedimentary deposits all around the interior of the boiler, showing the high and low-water marks. These indelible water lines gave evidence unmistakable, that the water had been too low. Since my attention was first directed, many years ago, to these peculiar high and low water deposit marks, I have personally inspected the internal condition of many hundreds of steam-engine boilers, and I have missed no opportunity of testing the accuracy of these indications of water-level, by a reference to other well ascertained facts, and have found that mutual accord which was to have been expected.

In the Jersey-street boiler, some of the most distinct, and probably the most recent of those water-marks were within twelve inches of the boiler bottom, at which point, and at least an equal distance below the proper level, it is extremely probable the sur-

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measure' be not assigned. "I know a very serious case of rupture of a new boiler, attended with loss of life, which was solely attributable to a bent spindle, in my opinion, * * * but I must confess that this conclusion,—mine as well as yours, being matter of opinion, simply—might be taken indifferently, according to the notion of the reader.

"I agree with you that '*sticking*' of safety-valves, properly so called, is extremely improbable."

face of the water was, when the explosion took place. *Now, it is to a deficiency of water to this extent, combined with a sudden opening of the safety-valve, causing a rapid ebullition, and a spreading of the water over the superheated side of the boiler, that I principally attribute the frequency of explosions.*

### COMPARISON OF THE AMERICAN EXPERIMENTAL EXPLOSIONS WITH ACCIDENTAL EXPLOSIONS.

We may now return to the American experiments, with the advantage of the illustrations afforded by the two Manchester explosions, in which, in the words of the committee, the "sort of bursting" produced in each case, was precisely of the same kind.

In the American report, speaking of the iron boiler, it is stated that "the explosion tore off one of the heads *b c* (Fig. 95,) of the cylinder, projecting the other parts of the boiler in an opposite direction, carrying with them, a portion of the distance, the iron cylinder forming the furnace, and scattering the fuel in every direction.

"The report attending the explosion resembled that from a small mortar fully charged; the steam mixed with the smoke was not considerable in quantity, and few marks of water were to be seen. The boiler-head was thrown fifteen feet, the boiler and spring register about six feet, and the furnace, weighing about forty-five pounds, was overturned and carried four feet. The pressure indicated by the register was eleven and one-fourth atmospheres, (about 154 lbs. per square inch.)

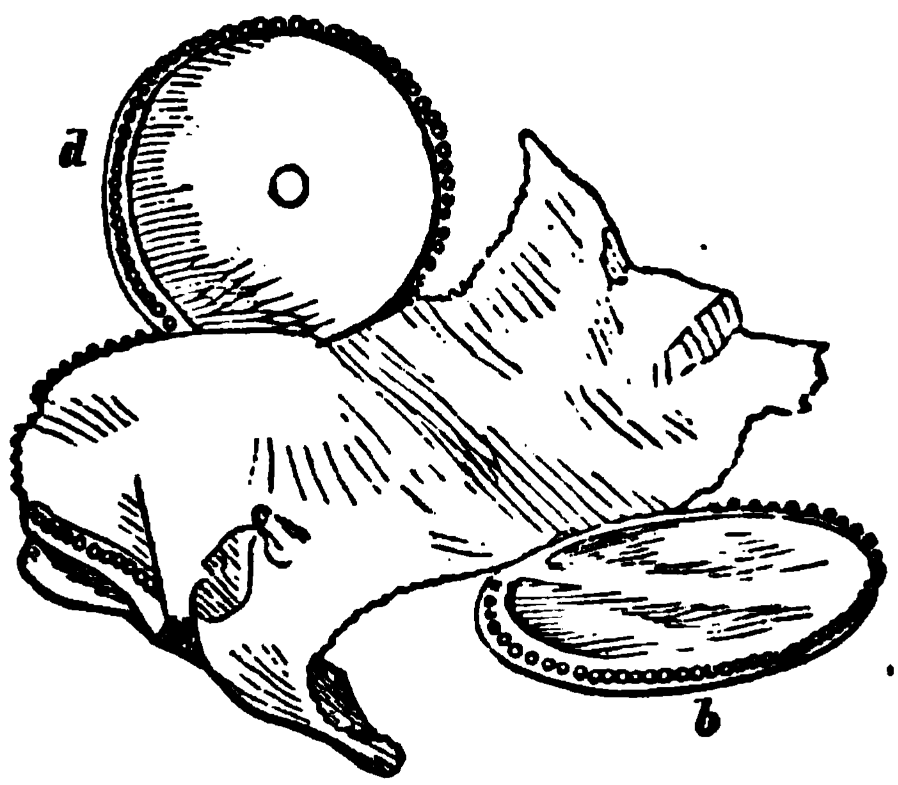
"In examining the boiler, it appeared that the head *b* which was thrown off, had first struck against the iron furnace, which had deflected it outwards; this is shown by the indentation *c* in the figure. This head was forced off all around, in the line of rivets which attached the head to the boiler, the metal remaining between the rivets being less than the space occupied by them."

The accompanying Fig. (96) will give an accurate idea of the appearance of the boiler after its rupture.

## LOSS OF WATER BY BLOWING OFF AND LEAKAGE.

The committee then goes on to give the details of an experiment with a *copper* boiler of the same diameter, and of similar construction, which was exploded by a pressure supposed to be of about sixteen atmospheres, after having failed in the first attempt owing to leakage, as in the former case. The sound or report was stated to be like that from an eight-inch mortar. The copper was torn from the heads, unrolled, and irregularly bent; adhering to the heads, for only a short distance, as shown in the cut (Fig. 96,) and the heads were bent outwards. The thickness of the copper at the line of rupture, varied from ·025 to ·035, say about 1-32 of an inch.

Fig. 96.




The description of the above carefully recorded experimental explosions, shows that the steam was allowed to rise gradually, in both cases, until the boilers gave way. This gradual and *slow increase* in the pressure of the steam, *was in great part caused by the leaks impossible to be avoided in the riveting of such very thin boilers;* a circumstance which enables us to compare these experiments with other experiments at boilers under different circumstances, but in very similar conditions as to leakage of water and steam, which we so frequently meet with in ordinary practice. A not very dissimilar condition is that of the continued escape of steam, from the safety-valve or otherwise, and the consequent loss of

water during the time an engine is standing, and the force-pump not at work, such as has been already described in speaking of the Cross-lane explosion. Another instance is the case of a locomotive when running on a railway with the steam either blowing off, or being continually consumed by the engine at a pressure or strain upon the iron very much greater than either of the Manchester explosions we have described, but with this important difference, that while the locomotive is running, the full supply of water is easily kept up. In nearly all explosions of locomotives that have hitherto occurred, which have been very few, and of these only a very small number have taken place while the engine was running, there has been always good reason for assuming a deficiency of water in the boiler.

There is another condition that admits of a comparison with the American explosion, and which is, perhaps, the most important of any yet enumerated. It is the condition of an ordinary stationary boiler when the water surface is allowed to become too low from unseen leakages at the *lower* part of the boiler at certain times when the engine is standing, and consequently the feed-pump not at work. It will be well to bear all particulars of frequent undue leakage in mind for future application, as they have an important bearing on the general subject of boilers in other respects besides those above named, and they have been entirely overlooked by the American committee.

It appears that both the American boilers exhibited proofs of the water having been too low at the moment of explosion. Speaking of the copper boiler, the report says:

"The marks of the sediment remained in the boiler, and indicated that the water was about *an inch deep* when the boiler exploded." Much more steam being formed, and more water left, at the moment of explosion, in the copper than in the iron boiler. It was also observed that the steam increased "more rapidly as the quantity of water diminished," and the committee add the following remark as a conjecture:

*"It is possible there may be a relation between the space occupied by the water and that in which the steam is formed, most favorable to the production of steam, and when this was attained a rapid rise of elasticity took place."*

It is much to be regretted that no further experiments were in-

stituted in the direction of this sagacious suggestion. The committee, however, were under the necessity, from the nature of their instructions, of investigating some particular averments of Mr. Perkins, together with some episodical refinements that seemed to have little connection with the great facts they were in quest of. In reading the above passage in italics, in the report, and knowing that this branch of the inquiry ended there, it is difficult to help lamenting that it is as if Columbus had turned back when he was within sight of land.

Nothing remarkable occurred previous to the instant of the explosion of the copper boiler, and the members of the committee employed in the experiments were engaged in observing the boiler at the instant it exploded. When "a dense cloud of smoke and flame, capped by steam, rose from the pit,* the stones and combus-

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* *Explosion at Brookes's Flax Mill, Bolton, July* 1, 1844.—Although some of the conclusions arrived at in the American report may admit of exception, evidences tending to corroborate the general accuracy of the committee's observations ought not to be withheld. So far as two or three instances of explosions go, I have had an opportunity of witnessing those appearances, which, to my mind at least, confirm the description given by the committee. As one example, I may refer to the explosion of a large boiler at the flax spinning-mill belonging to the late John Brookes, Esq., in Little Bolton, Lancashire, which I personally witnessed, at the distance of about three hundred yards from the mill, to which I was then on my way when the accident took place.

First, a column of dust arose to a considerable elevation, in which some of the timbers of the roof of the building which enclosed the boiler were seen flying in different directions. Then arose a cloud of smoke, which spread out above in a large black canopy. Through this a column of steam and water shot up to a very great height, which dispersed in moderately-large drops, like a shower of rain, in the direction of the wind, and to the distance of about four or five hundred yards from the mill. At the same time, as a column of steam continued rising from another boiler in connection with and nearly adjoining the one that burst, for about half a minute, and as the lower part of the cloud of smoke and dust began to clear away, flames commenced making their appearance, arising from a high building adjoining that which had been blown up along with the boiler,—and which, in fact, as I afterwards found, had been set on fire by the burning coals from the furnace of the exploded boiler being driven in through the windows of the lower story of the building.

The boiler was of the wagon form, about 27 feet long by 9 feet wide, and 10 feet deep, weighing probably about 10 tons, and called 40-horse power. The lower portion, reaching up to the top of the side-flues, about three-fourths of the whole, was thrown in a single mass to about 20 yards from its seat: while

tibles were widely scattered, and the boiler was thrown in a single mass about 15 feet from the furnace."

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the upper or semicircular portion, together with the steam-pipes, safety-valve, nozzles, and other attachments, were thrown to a great height, and fell in the adjoining street, the ground of which was at an elevation of more than 20 feet above the level of the seat of the boiler.

The circumstance in which this Bolton explosion differed from those in the American experiments is remarkable,—that is, in the report or sound produced. For if the report produced by the bursting of a very small boiler, only 10 *inches long by* 8 *inches in diameter*, was like that from the discharge of a cannon, what might we not expect from the explosion of a boiler 27 feet by 9, or about 5,000 times larger! But the fact is, that neither myself nor a friend whom I was in conversation with at the time, heard any *report of that kind* at all, but only a rumbling sound, such as might be supposed to arise from the cracking of the roof-timbers, the falling of the building, and the blowing-off of the steam from the other boiler, which had been working in connection with the one that exploded. There was a low, continued rumbling noise, as described by some who were nearer to the scene of the explosion when it commenced, but it was certainly not *loud*, and, indeed, scarcely audible to us at the distance before mentioned, although our attention was particularly directed to the cloud of dust and smoke which arose from the mill. It being not a little remarkable, also, that the subject of our conversation at the time was the deterioration to boilers from incrustation, and increased liability to accident from working higher pressure, which had then recently been adopted at this very mill on account of attempting to work the engines more expansively on the Cornish system, but without the strong Cornish boilers. The destruction in this particular case, in my opinion, being greatly increased by using Mr. Williams's patent system of smoke-burning, which required the keeping of a *thick* fire (over 18 inches), and a stream of cold air passing up behind the fire-bridge. The area of the fire-grate of the exploded boiler was about 60 square feet, consequently it was charged at the time of the explosion with nearly 100 cubic feet of burning fuel. The effect of the sudden dispersion of such a mass of fire may be easily conceived. That portion of the boiler-bottom which extended over the fire-place, about 8 feet square, was torn right across, nearly in a straight line from side to side, exactly at the position of the bridge, besides being ripped up on one side through the seating-plates, and across the front end at the angle over the fire-door. Thus this large portion, being liberated on three sides simultaneously, it was doubled back on the other seating, as on a hinge, or like the flap of a table, thereby opening out a hole of about 60 square feet in area, with an initial pressure of steam at about 20 lb. per square inch. And immensely reinforced as that pressure would be by contact with the burning fuel in the furnace, it is not difficult to divine the great force of the explosion, and the consequent disastrous results that followed.

This copper boiler was rent in the manner shown in the figure (fig. 96), giving way in an irregular line just above the probable water-line on the side of the boiler, but not conforming to it. The lowest points of the two heads of the boiler before the explosion were at *d* and *b* (see fig. 96, page 299).

## CONTRARY CONCLUSIONS DRAWN FROM THE AMERICAN EXPERIMENTS.

The American committee conclude their remarks on these experiments generally, by observing that "all the circumstances attending the most violent explosions may occur *without a sudden increase* of pressure within the boiler." This, no doubt, is true as a *possibility*, but it does not appear to me to express correctly the circumstances usually attending explosions in practice. The committee indeed do not say that it does do so, but such a conclusion is a natural inference from their averments. My experience, however, and a generalization of all the facts which have come under my observation during a large practice in boiler-engineering, con-

My first impression, on witnessing the commencement of the scene just described, was that it was the breaking out of a fire, and that indeed was the general impression of great numbers of the people in the streets of Bolton who were making their way to the scene of the catastrophe, until met by the crowd of operatives rushing out of the gates of the factory yard, many of them cut and bleeding from the effects of the broken glass windows which had been driven in upon the workers in several rooms of a six-story building situated close to the boiler house. It was through these windows that the burning coals from the large furnace were principally driven which set on fire the machinery inside the mill, where the consternation and rush to escape was very great, as may easily be supposed, there being in the whole factory about 540 people employed at the time.

Respecting the peculiar sounds or reports produced by boiler explosions, it may be stated that the strangest discrepancies occur in the statements of professed eye and ear witnesses of this and similar explosions. For instance, in this case, more than one party testified to having heard the report more than two miles off, like that from the discharge of an immense piece of ordnance. All the London papers, true to their character of exaggerators of every thing, had it that the people of Bolton were suddenly startled, as with a loud clap of thunder; and some of them stated that the *whole town was alarmed as with an earthquake!*—an opinion which the country papers also shared *after* the London newspaper reports reached them. R. A.

duct me to a different conclusion. My opinion is, that, *in the most violent explosions that have occurred, there is always a concurrence of circumstances attending them which show that a sudden increase of pressure within the boiler has taken place, either at or immediately before the moment of explosion.* And further, that without such concurrent circumstances, or some of them, the explosion would not have taken place at all.

## COMPARISON OF CONCLUSIONS.

If we briefly express the conclusion of the committee in similar terms to those used in the enunciation of our own theory it amounts to this, namely, that *all the circumstances calculated to produce an explosion may "occur" without an explosion taking place.* While, in opposition to this, I maintain that those same circumstances cannot "occur" *simultaneously* without an explosion being produced.

Considering both these conclusions as separate propositions, and one or the other to be proved by its general agreement with facts as they arise in other cases that come before us, we may begin by taking, as an instance, the first experiment with the iron boiler as given by the committee. Here there can be no doubt that all the circumstances which *they considered* to be necessary to cause an explosion existed, and yet no explosion took place. We, however, hold that no *sudden* increase of pressure took place, and therefore it was that, in the first instance, no explosion ensued. Thus we see that one of the most important circumstances is wanting. Let us, however, see what all the facts were, by which circumstances were so constituted as to fail in producing the explosion. In the first place, the boiler was without a safety-valve, unless the leak in the riveting may be considered as having the effect of an imperfect one. Secondly, the water surface was proved to be *considerably below its proper level,* and therefore the upper portion of the sides was exposed to the risk of becoming overheated.

Now, here are facts constituting two predisposing causes,—the shutting up the steam and the deficient depth of water. But the first was confessedly imperfect, the leak allowing the steam to blow off, from the commencement of the experiment, so fast, that it could not be raised to the bursting pressure, even gradually,—not a bad illustration, as the result proved, of the *safety* of a badly

fitted safety-valve, or one in bad order, not tight. And the other fact, we may also show, was only imperfectly calculated to produce a *sudden increase of steam-pressure*, in the only way that such a thing can be conceived to be possible; that is, by the water left in the boiler being, by some impulse, put bodily into motion, and caused to flow over the overheated metal. That the overheating of the sides, to some extent, took place, there is no reason to doubt, although there is great reason to doubt that the quantity of water left in the boiler was sufficient for overflowing entirely the overheated part, even if such impulse had been given to the mass of water as would have arisen from a slight increase or enlargement of the leak, and which a little increase in the pressure from a more rapid production of steam would have produced.

## CONCURRENCE OF CIRCUMSTANCES ATTENDING THE FIRST EXPERIMENTAL EXPLOSION.

Now let us examine what changes of circumstances were made at the second trial with the iron boiler, when, at last, an explosion did "occur." The report states that the boiler was "replenished with water," and we may safely infer that it would not be scantily replenished, seeing the committee considered the previous deficiency to be the cause of the failure of the first experiment, or, at least, one cause of its requiring to be repeated. Then the boiler was "settled *lower into the fire*, which was again urged," and the whistling sound of the steam through the leak, which before had increased, "seemed constant." Soon after this, the explosion took place.

Here we cannot fail to remark, that the two main circumstances, contributing to bring about the explosion, the pressure and the low water, were present in the same degree, or nearly so, as on the first trial; although the pressure might be a little higher, and therefore calculated to produce, as it certainly did produce, an *enlargement* of the leak or fracture in the riveting; which enlargement, in its turn, became the *third* or *actuating circumstance*, which, concurring with the other two, caused the explosion of the boiler to take place on the second trial.

The reader who has followed me thus far will now be in a posi-

tion to enable him to make a practical application of this reasoning to the case in hand.

### PRACTICAL APPLICATION OF PRECEDING PRINCIPLES.

Settling the boiler "lower into the fire," besides raising the pressure of the steam higher in the same time, would also, from the increased expansion of the overheated plates, tend to diminish the leakage, thus diminishing the waste of water and lowering the water-level more slowly, consequently giving more time for the sides to acquire an undue degree of heat from the nearer proximity of the fire.

The proved effects arising from overheating the sides, or other parts of a boiler, to a temperature of from 400° to 500°, are now well known to be—first, the repulsion of the water from the overheated surface, producing a *decreased* amount of steam; but immediately afterwards, as the temperature of the metal is reduced down to the point of maximum vaporization, or a little below 400°, by *any thing causing the water to flow over the overheated parts*, a sudden and greatly *increased* production of steam. Now, had there been a safety-valve attached to this experimental boiler, and had it been suddenly opened either by the pressure of the steam or by design, this flowing of the water over the sides would have taken place, according to the theory here enunciated, precisely in the same manner as it was in reality produced by a *sudden enlargement of the leak* or defect in the riveting; and from which the rent or rupture of the whole boiler might have proceeded instantaneously. The enlargement of the leak in this case, which a slight increase of pressure was sufficient to effect, may in fact be compared to the pulling of the trigger of a gun overcharged, and ready to go off. Thus, also, according to my views, a good safety-valve, if brought into action, would have accelerated the explosion of this boiler, or rather have caused it to take place during the first trial. The opening of any ordinary induction-valve for blowing through, for the purpose of starting an engine, or any other sudden liberation of the steam, from any cause whatever, would have had the same effect. Any thing in fact tending to a disturbance of the equilibrium, or level of the water inside the

boiler, would have answered the purpose. This disturbance, we are bound to believe, was effected by the rending of the boiler at the leaky or defective seam of rivets on the second trial, which caused the rise of the water-level over the hot metal, and a consequent sudden production of steam, by which the explosion of the boiler was finally produced.

## RECAPITULATION.

Respecting the peculiar phenomena relating to the repulsion which takes place between highly heated metal and water, known of late years as the "*spheroidal* condition of water," and which I consider one of the corner stones of my theory of explosions, I speak more fully in the accompanying note.* The following is a

* *The "Spheroidal Condition" of Water.*—The term "*spheroidal*" was, I believe, first applied some years ago to that particular condition water is in when repelled from a hot surface in the form of roundish drops, by Mr. J. E. Bowman, then Professor of Chemistry at the Royal Institution, Manchester, and since of King's College, London. This was on the occasion of his reading a lecture on the subject of steam-boiler explosions, in the above institution, in the course of which he was the first, perhaps, in this country, to give an account of, as well as to show experimentally some of those remarkable properties of water and other liquids when projected into red-hot vessels, since made popular by some curious performances at the meetings of the British Association, and more recently at the British Institution, by M. Boutigny, of Evreux, in France.

This gentleman, who had been some years engaged in the prosecution of researches connected with the subject, was, until the delivery of Mr. Bowman's lecture, above referred to,* and its subsequent publication, generally supposed to be the first who had attempted to "account for explosions on the supposition that water in them passes, under certain circumstances, into the spheroidal state." Sufficient evidence, however, was furnished to Mr. Bowman on that occasion, that I had been many years well acquainted with the principle of the spheroidal condition of water in boilers, its tendency to create priming and to promote explosions, although I had never thought of giving it that or any other distinctive appellation. That I had several years prior to its no doubt independent discovery by M. Boutigny, also applied it to account for some of the explosions of steam-boilers, was a fact which Mr. Bowman very handsomely acknowledged both in his lecture, which was followed by a public discussion on the subject, and also in his pamphlet, by quoting at length passages containing evidences thereof from a pamphlet of mine, published in 1836–37. An instance of liberality and justice so honorable, though rare, among scien-

* "On some remarkable properties of water and other fluids, with reference especially to the causes and prevention of steam-boiler explosions." By John Eddowes Bowman. London: J. W. Parker, 1845.

recapitulation of the circumstances already mentioned as among the most prominent causes of boiler explosions.

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tific writers, that I cannot omit this opportunity of publicly acknowledging it. And I may here notice the fact that, although partly printed in 1836, my book was written and the manuscript perused by several friends nearly three years before that time. The complete application of the discovery to the theory of explosions was in reality made by me previous to 1830, when, in conjunction with my then partner, Mr. Henry Wright, engineer, of Manchester, I made application for a patent, embodying the principle of the repulsion of water from over-heated boiler bottoms and front tube-plates of locomotives being one cause of the priming of steam-boilers, as well as causing explosions. During the years 1831 and 1832, it is quite notorious, in Manchester, that I frequently exhibited the principal experiments relative to it, in explanation of the bursting of boilers. Small *glass* boilers were purposely exploded with that view in the presence of well-known parties in numerous instances.

The simplest mode in which those unused to experimenting may most conveniently at any time readily demonstrate the "spheroidal condition of water," is that of heating the bowl of a large teaspoon over the flame of a candle until water runs off without *wetting* it. Then, by the aid of a dropping tube, or a quill, or any other means of measuring into the spoon successive drops of water of the same size, the leading facts of the repulsion of liquid in the form of beads or spheroids become very apparent. Thus a moderately small-sized bead or globule of water, when the spoon is very hot, will be observed to rotate rapidly on its axis, all the while moving quickly about, supported by a thin film of steam, and occupying half a minute or more perhaps before it is entirely evaporated. If now, without re-heating the spoon, and *while, in fact, it is rapidly cooling*, we place another drop of water of exactly the same size in the same position as the first, it will, after assuming the same spheroidal appearance, rapidly diminish in size, and evaporate entirely away in two or three, or, at most, in a very few seconds. A third drop so placed will be found generally to disappear in less than one second; or, if the experiment be carefully managed, the last drop will be made to vanish instantaneously and without assuming the globular or spheroidal form. The temperature of the metal of which the spoon consists will then of course be that of maximum vaporization, and which is usually found to be considerably under 400° Fah. By the American experiments it was found to be about 350°, and the temperature of perfect repulsion of drops of water, projected into an iron bowl a quarter of an inch thick was 405°. The committee also refer to a series of experiments by Professor Johnson, who places the maximum evaporating point at between 304° and 320°, and in their general view of the facts detailed, state that the repulsion between the metal and the water is perfect at from 20° to 40° above the point of maximum vaporization, at which temperatures the water does not wet the metal.

Some of the conclusions arrived at by the committee are as follows:

1. The temperature of maximum vaporization, both in copper and iron, is

*First,*—The overheating of the boiler bottom or sides, or the tops of the internal flues or furnaces, which may be brought about by the water level becoming accidentally too low. The bottom of the boiler, however, may become overheated from many causes without any undue depression of the water level. One is the interposition of indurated sediment, furr, or scale, between the water and the metal. Another is the operation of a powerful blast or

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lower as the surface of the metal is smoother, and the amount of vaporization in a given time is much diminished.

2. The temperatures of maximum vaporization, for copper and iron in similar states of surface, differ between 30° and 40°, the iron having the higher point.

3. The time of vaporization, at the maximum, is less in the copper than in the iron, in the ratio of about 2 to 1, probably, nearly in the ratio of the conducting powers of the two metals for heat, which are as 2½ to 1. (See American Report, page 47.)

It must be observed that the above results are from drops, or small quantities, of water, under atmospheric pressure only. And, however interesting they may be in a philosophical point of view, they cannot be said to touch the practical question of the effect of large quantities of water brought suddenly into contact with hot metal, in producing explosions.

Accordingly, some experiments with cast-iron bowls, half an inch thick, containing large quantities of water, placed over charcoal fires, indicated that the highest point of greatest evaporation was placed, at least, about 200° below red heat in daylight, and in the most favorable circumstances, varying from 550° to 600° Fah. for wrought iron, and from 470° to 526° for copper.

In the course of the experiments of the American Committee, it was observed that, with other liquids, alcohol for instance, at a certain temperature of the dish, that of the spheroid became stationary at 169½° or 170°, (the boiling-point being 173°,) and that it could not be raised higher; indeed *the temperature of the spheroid became lower* as that of the dish was *higher*. In my own experiments, that point not appearing to me then to have any direct useful application, I had only generally remarked that the temperature of the globule of water must be lower than 212° from the fact that it did not boil. And it is entirely to the delicately manipulated experiments of Messrs. Bowman and Boutigny that we are indebted for a knowledge of the fact, that the temperature of a spheroid of water is invariably constant at 205°, or 7° below its boiling-point, however hot the crucible which contains it may be. Thus, also, a spheroid of *alcohol* always stands at 170° or 3° below its boiling-point; one of *ether* is always 5° below, or 95°; and liquid *sulphurous acid* which boils at 14°, never reaches so high even as that low temperature when in the spheroidal state, but continues far colder than melting ice, even though the crucible in which it lies be all the time *at the most intense white heat.* It was on this principle that M. Boutigny contrived the feat of freezing water in red hot crucibles, and afterwards that of handling melted cast-iron. R. A.

draught through the fire, by which such a quantity of steam is generated over a small portion of the boiler bottom, that the water is partially or wholly driven away or repelled therefrom, in the "spheroidal condition" referred to; and is often *produced by currents of air for smoke-burning purposes, admitted in an injudicious direction.*

*Secondly,*—The giving way of some small portion of the boiler, which would not of itself constitute an explosion, but which would be sufficient to liberate a large quantity of steam or water, and create a sudden disturbance of the water-level, which circumstance concurring with the other conditions named, a sudden rise in the pressure of the steam would result, and an explosion ensue.

## DEFECTS PECULIAR TO BOILERS COMPOSED OF RIVETED PLATES.

Ordinary observers sometimes make the remark that, in comparison to the frequent instances of boilers bursting, we seldom hear of the bursting of guns; and among sportsmen, never perhaps unless overcharged. Without noticing the truth of the allegation, which is perhaps not quite admissible, there is one circumstance which renders the comparison unfair towards the boiler. A gun,—a fowling-piece, for instance,—though said to be in constant use for a whole day, is only subject to pressure for a fraction of a second at each discharge, not in all occupying many minutes, whereas the boiler has to resist the pressure, and its variations continuously. The general cause of the explosion is the same in both cases. The boiler like the gun is too weak for the charge it contains *at the moment of the explosion.* "Why then," it will be objected, "can you not do as the gunmakers do—make your boiler stronger, with an ample margin, for covering errors of calculation, and unseen defects in the material; and then, after a *double* or *treble* proof, ought not a boiler to be as safe at least as a gun?" This semi-military way of putting the question, is the language, and conveys the notions, not of military but of many civil-engineers and boiler makers of the highest practical talent, and therefore deserves a categorical answer.

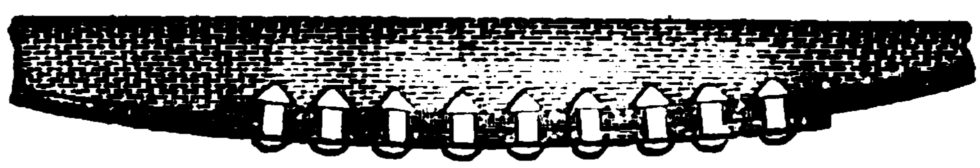
In the first place, putting out of consideration *cast-iron* boilers, because they are now seldom or never used, although much might be said in their favor, I answer that a boiler *composed of plates* of wrought-iron *riveted* together, and overlapping each other at their

edges, is in a very different condition to a gun or cannon composed of one nearly uniform piece of metal. The latter quickly acquires a uniform temperature after any disturbing cause, and a more uniform contraction or expansion throughout its whole substance is the result. The boiler, however, is necessarily exposed to much greater inequality and extremes of temperature; it is consequently liable to correspondingly greater variations of expansion and contraction; and it will not be difficult to show that the great contraction and expansion of this compound and complicated structure of plates and rivets forming the boiler, and which is going on continually while the boiler is at work, as necessarily tends to tear it in pieces, even without much assistance from the pressure of the steam.

As an example, in order to illustrate the destructive effects produced by the continually varying expansion and contraction going on among the plates of a riveted boiler, I may take the common case of one twenty feet long by six feet diameter, with the fire under its bottom, and containing an inside tube or flue. Both boiler and flue being composed, as is usual, of, say ten rings of plates of about two feet long each.

Now, on the first application of the fire to the bottom of such a boiler, and before there is any pressure of steam at all, each of these plates immediately acquires some intermediate temperature between that of the fire outside and the water inside the boiler. These two temperatures may be fairly considered to average about 1500 and 100 degrees respectively, to begin with. The external surface of the wrought-iron plates were single, and the whole substance of the outside portion of the plates where *double* or *lapped* over the other, tending to the higher, and the inner surface of the boiler bottom tending to the lower temperature. The consequence of this is that the expansion of the outer exceeding that of the inner surface, the boiler bottom becomes to some extent *convex outward*, or towards the fire in a longitudinal direction; thus,—

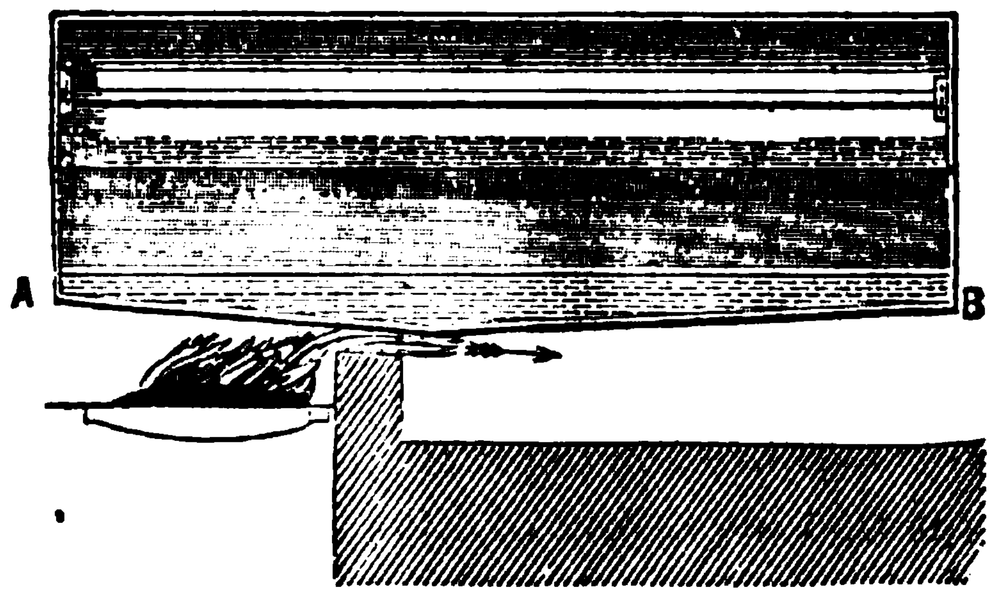
Fig. 97.



The curvature of the plates is purposely exaggerated in this

figure in order to show more clearly the form the boiler bottom *tends* to assume theoretically, and not its extent, on the application of the fire every time the steam is to be got up; and this on the assumption that the joints of all the plates are perfectly and firmly riveted, and each plate of *exactly equal strength throughout.* This however may be considered an almost impossible condition in practice. There is always some one or other of the seams of rivets less capable of affording resistance to the immense force of expansion than the rest, and these parts will therefore be the first to give way. The consequence is that the boiler bottom more generally assumes the form represented in Fig. 98.

Fig. 98.




Should there be any pressure of steam at all in the boiler, and the plates be of equal strength, and equally acted on by heat, of course the point of greatest depression would be near the middle of the length of the boiler. The greatest heat, however, being in the vicinity of the fire-bridge, is sufficient to determine the position of this point at the nearest seam of rivets to the bridge; and there in fact this depression is usually found. When permanent, it is then commonly said by the stoker, "The boiler bottom has come down."*

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* Although this expression is usually applied to wagon-boilers, the case is in point of fact one of *collapse*, similar to that of a large fire-tube of a Cornish boiler. The subject is treated on more at length in my "Essay on the Boilers of Steam-Engines," 1839, page 241.

As this work has been several years out of print, I give the following extract from a *second edition*, which I have had some time in preparation, together with an additional volume of "Notes and Illustrations."

With respect to the extent of the depression liable to be produced from this cause. If we take the difference of temperature between the external and internal surfaces of the boiler bottom, at 500°, and allowing iron to expand at ·00007 of its length, for every 10° of Fah., or ·00007 × 50 = ·0035 of its length for 500°, this will correspond to ·84, or nearly an inch of expansion in the total length of the boiler bottom externally.

The immediate action of the fire is, of course, to bend each plate separately, supposing the latter to be clean. But a boiler has commonly some sediment deposited from the water, and any of the ordinary deposit, however thinly spread over the bottom of the boiler, being a very bad conductor of heat, permits the temperature of the plates to rise higher, extending through their whole thickness, and expanding the plate, in some cases, to double the amount supposed above. This condition greatly modifies the heat in bending the plates, which become more extended in length, and it adds considerably to the curvature of the boiler bottom. Accordingly, we constantly find, at particular times, a very serious deflection of boiler bottoms downwards at about the middle of their length. The depression commonly admits of accurate measurement, to the extent of a quarter of an inch or less, by

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"It may be asked, if our theory of steam-boiler explosions be correct, how it is that we have not many more of them, as the causes to which they are ascribed may seem to be of almost every day occurrence? The answer is, that the *bursting of boilers* is also a matter of every day occurrence, to an amount which the public generally are altogether ignorant of. To be sure these burstings are not generally called *explosions*, although in reality they are so, being different only in degree. It would not be difficult to prove that two or three of these minor explosions occur in Manchester every week; but when no fatal consequences ensue, and no particular damage is done to any adjoining property, of course the circumstance never gets into the newspapers, and no public notice is taken of it.

"Usually, the affair has quite another name when it occurs with a wagon-boiler; it is then said that the "boiler bottom has come down;" in other words the concave bottom is forced down into a convex form, and sometimes the sides are in like manner forced outwards, about the middle of the length of the boiler. The consequence in the least violent of these cases is, that the boiler is lifted up a few inches from its seating by the bottom striking upon the top of the fire-bridge. We also usually find every seam of rivets violently strained, so that the water runs through the boiler bottom like a riddle although there is seldom a hole of more than a few inches in area." R. A.

placing a loose brick on the top of the bridge, just a little *out of contact* with the plates. And it regularly takes place in all boilers, to a greater or less extent, every morning *before the steam is up*, and before there is any pressure whatever, excepting what arises simply from the weight of water in the boiler.

Very little observation will convince any one that the peculiar action I have been describing really takes place. The fact is notorious that all boilers are more or less leaky when the fire is first applied to them for getting up the steam; possibly the leak is so minute, in some cases, as to be scarcely discernible; but, generally, the leakage is sufficiently apparent when there is a clear fire under the boiler.

Now it is well known that, so soon as the water inside the boiler becomes heated, the leakage decreases, and, by the time it is boiling, and the steam begins to rise, every leak in the boiler bottom, except those that are running a full stream, is stopped, or nearly so. The cause is, clearly, that the heat, so soon as ebullition in the water commences, is carried off, by the formation of steam, from the inner surface of the plates, as rapidly as it is transmitted through them from the fire; and, therefore, the temperature of the plates falls, or becomes uniform, and, consequently, they again assume their original dimensions. The usual expression of the stoker, then, is, that the *leaks* have "taken up," and, by the time the steam is up, or sooner, the boiler is "as tight as a bottle." It is, however, the boiler bottom that is "*taken up*" by contraction and an equalization of temperature on each side of the plates. I am aware that this result is commonly ascribed to sediment being driven into the joints of the plates by the pressure; but the stoppage of the leaks commences before the steam is up, and the same phenomenon occurs in boilers which are quite new, and which contain no sediment.

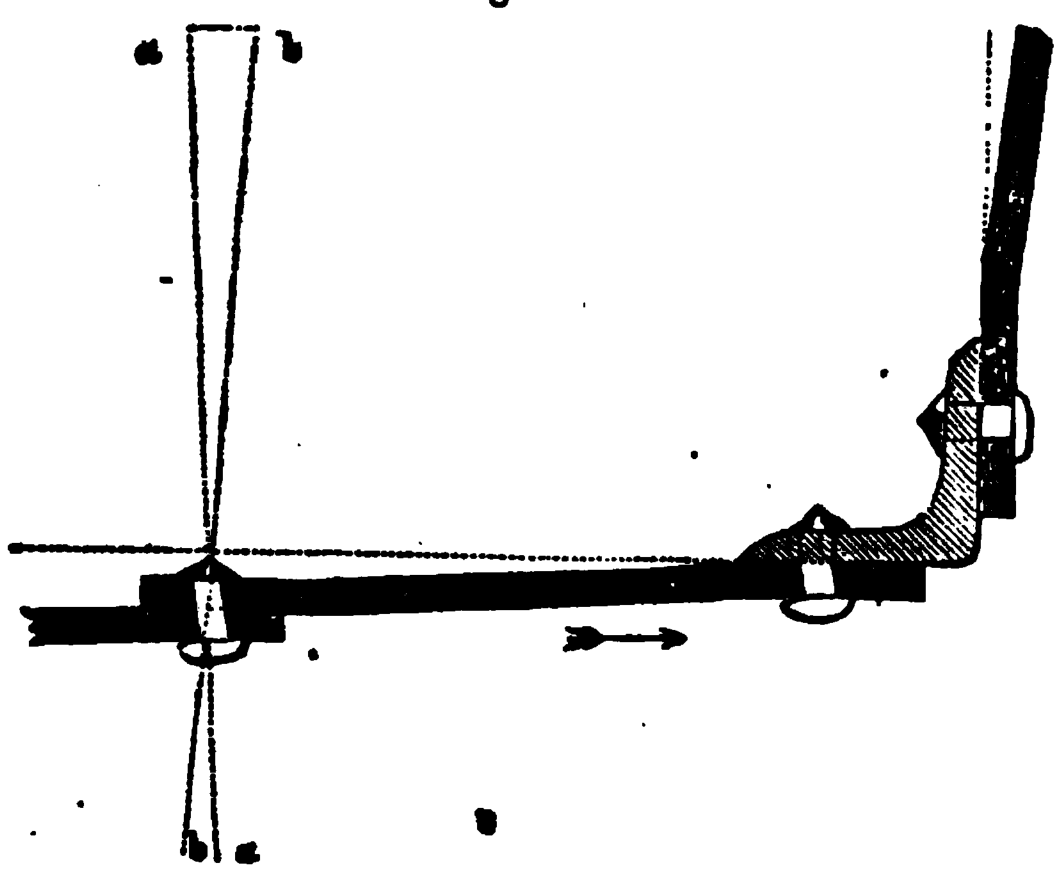
So far as a leakage of the kind just described may diminish the quantity of water in a boiler, it is obvious that it will be generally inconsiderable. A constant daily repetition of this process, however, causes much oxidation of the iron in the vicinity of the leaks and induces weakness in some particular direction across the boiler bottom, which ultimately causes large openings between the plates, and, then, great loss of water results. And how the sudden loss of a large quantity of water in a morning, or at other

times, before the steam is up, is likely to end in a violent explosion, at or about the time the engine starts work, will be sufficiently apparent from the explanations already given.

### HOW CHANGE OF FORM PRODUCES FRACTURE.

It is evident that a greater amount of expansion and contraction will be produced at those joints of the plates which are immediately over the hottest parts of the fire than elsewhere. Suppose, for the present, that the whole of the plates in the boiler bottom are heated uniformly; then, since the ends of the boilers are firmly braced to each other by means of the internal flue-tube, as well as by the upper half of the cylinder, neither of which are so much affected by the fire, it is clear that the expansion of one part of the boiler is resisted by the other part. The greatest strain from the expan-

Fig. 99.




sion of the boiler bottom will be at the angles A and B (Fig. 98.) at which points, the rivets, (if immovably fast in the angle-iron,) must have a tendency to bend outwards from the longitudinal thrust of the plate in that direction, as in Fig. 99, which is an enlarged representation of the angle B in Fig. 98. The plate will also, sometimes, act as a lever in wrenching off the head of the rivet; or, as usually happens, by successive operations of this kind, the rivet-holes in the plates become permanently enlarged, and

break out. For example, so soon as the water becomes sufficiently heated to cause ebullition to commence, however slightly, the temperature of the plates immediately falls to 212°, or to such a degree as corresponds with the boiling-point at the time. And this point being attained, of course contraction of the bottom-plates immediately ensues, as before described, co-equal with the previous expansion. The thrust at the end rivets now becomes a drag in the contrary direction, or, as shown by the position of the lines *a a* and *b b*, in Fig. 99, which represent the directions to which the varying position of the rivet respectively inclines, according as it is acted on by the expansion or the contraction of the boiler bottom.

If the rivets do not always give way, they enlarge the rivet-holes, which, by this alternating action, become oval or lengthened in the direction of the strain, and, ultimately, cracks are formed between the rivet-holes and the edges of plates, as shown in Fig. 100, which is a plan or top view of Fig. 99.

One object I have in view here is to show that severe strains upon the rivets of a boiler, arising from undue expansion and contraction, may be increased by the thickness of the plates, and that the destruction of boilers from that cause is not confined to those

Fig. 100.

formed with angle-irons and flat-ends, but extends also to those made with hemispherical or "egg" ends, which are ordinarily considered superlatively safe high-pressure boilers. Such boilers are usually of less diameter, and are, consequently, of greater length, on which account they are more particularly obnoxious to the defect I have been treating of, arising from a proportionably increased amount of expansion and contraction.

As a practical example, I shall conclude by describing a boiler of this kind, which came under my observation a few years ago in London.

This boiler was three and a half feet diameter by thirty feet long, and set up with the ordinary wheel-draught, which is a very common, though a very improper mode of setting a boiler of so small a diameter. The consequence was, that, in order to obtain sufficient space for draught in the side-flues, the brickwork had to be carried up considerably above the centre, and the boiler was finally covered over with brickwork; a dangerous practice, though extremely common.

The reason for covering boilers in this way is, of course, to retain the heat, which it certainly does, but such a covering may be very detrimental to the durability of the boiler. Thus, when the fire is under the boiler, the temperature of the boiler bottom may not generally be more than about 250°, while that of the side-flues cannot be less than 500° or 600°, and the brickwork resting on the top of the boiler is seldom less than 350° or 400°, as I have frequently ascertained, and of course the iron in contact with it will be of the same temperature, except so far as the heat is carried off by the steam in contact with the metal. Now here may easily be a difference of 200° or 300°, causing a considerable amount of expansion in the top of the boiler, and a corresponding strain upon the rivets in the boiler bottom. But supposing the boiler to be emptied by running out the water at the end of the week for the purpose of cooling and cleaning it out, or of cleaning the flues; and further, for the purpose of cooling it quicker, suppose that a quantity of *cold* water is immediately run into the boiler, and let us see the extent of the evil which takes place then. The hot brickwork will retain the upper half of the boiler, upon which it rests, at full stretch; while the lower half, at least so far as the cold water extends, suddenly contracts, and, instead of 200°, we may have a difference of 400° between the top and the bottom of the boiler, equivalent to about an inch in the whole length of the boiler.

As near as could be judged, on close examination, this was the precise extent to which several openings in the seam across the boiler bottom amounted to collectively. One or two of the dislocated parts becoming jammed and retaining their positions, permitted of exact measurement.

This gradual disintegration of a boiler has no doubt been frequently observed by others, although not remarked upon. This particular example occurred at a factory where it was the custom to clean out one of the boilers every Sunday morning; for which purpose the stoker commonly filled the boiler he intended to clean immediately after letting out the hot water. And the case is adduced as an example of those cases where for years very great expenses were incurred in repairing and re-making the boilers without the cause of the defect having been discovered. Since, however, that practice of filling the hot boiler with cold water has been discontinued, although the boilers are now of thinner iron, larger diameter, and worked at higher pressure, a boiler-mender is scarcely ever required on the premises.

## AMERICAN EXPERIMENTS ON EXPLOSIONS,

Made by order of the Treasury Department of the United States, in which, among other instructions on the subject, directions were given—

"*To observe accurately the sort of bursting produced by a gradual increase of pressure within cylinders of iron and copper.*

"It has been contended by some, that ruptures produced by a gradual increase of pressure within steam-boilers, do not bear the character of explosions, but that a mere rending takes place, giving escape to the contents. This has been assumed to be especially the case with copper boilers. To make the observation required by the above question, cylinders of iron and copper were prepared, of sufficient size to make a small thickness of material answer for rending, by a pressure which was easily attainable. Two experiments made, one with an iron and another with a copper cylinder, afforded so direct an answer to the query that it was not deemed necessary to carry the experiments further, especially as they were tedious, and not without danger. A further experiment, of the same tenor, resulted from a trial of Perkins's assertion in regard to the effect of making an opening in a vessel containing water and heated to a high temperature.

"The boilers used were cylindrical, eight and a half inches in diameter, and ten and twelve inches respectively in length, of iron

·02 inch thick, and of copper ·03 inch thick, having iron heads ·05 inch thick, to which the convex surface was fixed by iron rivets, placed nearly touching each other. A single opening in the middle of one of the heads of each boiler was provided to introduce the water, and was furnished with a screw, into which to insert a tube and piston, connected with a small spring weighing-machine, which is represented at *a* in the cut on page 293. Upon the cylinder of this machine a ring was placed, which was movable along the cylinder by a slight pressure. This ring was forced towards the end of the cylinder nearest to the boiler head as the spring was bent; and remaining in its place when the spring relaxed, served to register the maximum pressure to which the piston had been exposed previous to observing it.

"The iron boiler was placed in a heavy cylinder of wrought iron, which served as a furnace, the axis of the boiler being nearly horizontal, and that of the furnace cylinder vertical. The boiler, having been half filled with water, was placed upon a fire of charcoal, and when the water boiled the register-machine for the pressure was screwed in.

"The place selected for the experiments was in a deserted quarry on the banks of the Pennypack, near Holmesburgh. The high bank served as a protection, by the aid of which the experiments were viewed with little danger. A wire and cord were attached to the head of the boiler, to draw it from the fire when the latter required to be replenished. A leak in the riveting of the iron boiler allowed so much steam to escape that the boiler did not give way on the first trial. As soon as the escape of steam was observed to cease, the boiler was removed from the fire and again half-filled with water. The fire was urged, and the boiler settled lower into it: and by once replenishing the fuel, without removing the boiler, an explosion was produced. Part of the committee were engaged in observing the progress of the experiment at this moment. The fire was near the middle line of the boiler, burning not strongly near that line, but very rapidly below the boiler. The steam issued freely through the leak before alluded to, and the whistling sound which it produced, and which had increased gradually in strength as the experiment progressed, seemed constant. The length of time during which the steam had escaped showed the water to be low, and induced the supposition that a

second time the object would fail,—when an explosion occurred. The explosion tore off one of the heads, *b c*, of the cylinder, projecting the other parts of the boiler in an opposite direction, carrying with them for a portion of the distance the iron cylinder forming the furnace, and scattering the fuel in every direction. The report attending the explosion resembled that from a small mortar (eprouvette) fully charged. The steam mixed with the smoke was not considerable in quantity, and few marks of water were to be seen. The boiler-head was thrown fifteen feet, the boiler and spring-register about six feet, and the furnace, weighing about forty-five pounds, was overturned and carried four feet. The pressure indicated by the register was eleven and a quarter atmospheres.

"In examining the boiler, it appeared that the head, *b*, which was thrown off, had first struck against the iron furnace, which had deflected it outwards. This is shown by the indentation, *b c*, in the figure. This head was forced off all around in the line of rivets which attached the head to the boiler, the metal remaining between the rivets being less than the space occupied by them. The convex surface and the other head were thrown likewise against the furnace, and the head indented at *d e*, overturning the furnace and carrying it four feet; as already stated. The boiler finally struck against the side of the bank of earth. The piston of the weighing-machine was somewhat bent in the experiment.

"The circumstances of this experiment show that the steam rose quite gradually on account of leaks in the boiler, increasing probably *more rapidly as the quantity of water diminished*, the intensity of the fire meanwhile increasing; that, at a certain period, the tension within had attained about eleven atmospheres, when the boiler *exploded violently*.

"The accompanying figure (95) will serve to give an accurate idea of the appearance of this boiler after its rupture.

"The cylinder of copper, before referred to, was next put in the place of the iron boiler, and the fire again kindled,—the general arrangements being as before described. This boiler being longer than the former, would not descend so far into the furnace, and an attempt to raise the steam sufficiently high to burst it failed. There was a considerable leak in the junction of the curved surface with one of the ends. When the water was nearly exhausted,

the fire having passed its period of greatest heat, the cylinder was removed and water again introduced, filling about three-fourths of its capacity. A new furnace was constructed of stones, allowing the boiler to rest more closely upon the fuel, and affording a screen from the wind, which was blowing quite strongly. The part of the boiler in which the leak had been observed was turned downwards, but a similar escape was found for the steam in the part now uppermost. The tension of the steam appeared to increase very slowly, and the fire passed its best action without effect. It was renewed, and as the water became lower the tension of the steam increased considerably. As before, nothing remarkable occurred previous to the instant of explosion, and the members of the committee employed in the experiments were engaged in observing the boiler at the instant it exploded. A dense cloud of smoke and flame, capped by steam, rose from the pit; the stones and combustibles were widely scattered; and the boiler was thrown in a single mass about fifteen feet from the furnace. The noise attending this explosion was like that from the firing of an eight-inch mortar.

"The boiler was rent as shown in the accompanying figure (96), giving way in an irregular line just above the probable water-line on one side of the boiler, but not conforming to it. *d* and *b* were the lowest points in the two heads before the explosion. The sheet of copper was torn from the heads, unrolled and irregularly bent, adhering to the heads for only a short distance near the top of each; and the heads were bent outwards. The thickness of the copper along the line of rupture varies from ·025 to .035 of an inch, and the metal appears to have been highly heated at one end of the torn portion. The piston of the spring gauge was bent, the screw which attached it to the boiler broken, and the whole instrument otherwise injured. It appeared that the wire intended to draw the boiler off the furnace had slipped and impeded the action of the piston, so that no register of the amount of force producing this explosion was obtained.*

* "Assuming the strength of copper at 36,000 lbs. to the square inch, and that it was uninjured by the heating,—neglecting also the effect of temperature,—the bursting-pressure appears by calculation to have been about sixteen atmospheres. It was no doubt less than this."

"The circumstances, as before, show that the steam was allowed to rise gradually until the boiler gave way. It is possible that there may be a relation between the space occupied by the water and that in which the steam is formed most favorable to the production of steam, and that when this was attained a rapid rise in elasticity took place; but there were no circumstances observed which would confirm such a view, and if it were correct, it would only affect the conclusion as far as the increase of tension might have been rapid from such a cause.

"As in the former case the marks of the sediments remained in the boiler, and indicated that the water was about an inch deep when the cylinder exploded. Much more steam was formed, and more water left than in the first experiment.

"These experiments, together with the one referred to in a subsequent part of this report, *are direct and conclusive*; they show that *all the circumstances attending the most violent explosions may occur without a sudden increase of pressure within a boiler.* There can be no doubt, however, that if particular portions of a boiler are much weaker than other parts, they may give way in time to prevent such a catastrophe."

(From "REPORT of the Committee of the Franklin Institute of the State of Pennsylvania for the promotion of the Mechanic Arts, on the EXPLOSIONS OF STEAM-BOILERS. Part I.—Containing the first report of experiments made by the Committee for the Treasury Department of the United States." *Philadelphia*, 1836.)

# CHAPTER XXVIII.

## RULES FOR CALCULATING THE CHANGE WHEELS FOR SCREWS ON A TURNING LATHE, AND FOR A WHEEL-CUTTING MACHINE.

HAVING long felt the want of a treatise like the present, on a subject hitherto overlooked, or, at all events, barely mentioned, by all mechanical authors, I have been induced to publish the results of my experience, in the hope that they may be of some benefit to others.

I am aware that tables have been calculated, and that they are in use in many workshops; but they are only adapted for screws of a regular pitch, as it is almost impossible to have tables which would meet every case of irregular screws.

I trust, therefore, that the rules which I have laid down will enable any one to calculate the proper change wheels without difficulty; and that they will be the means of saving many hours of valuable time, which is now wasted in vainly endeavoring to find the right wheels, which, to the uninstructed workman, must always be a matter of chance.

### ARITHMETICAL SIGNS AND THEIR EXPLANATION.

$=$ Sign of Equality, 12 inches $=$ 1 foot.

$+$ Sign of Addition, or *plus;* $2 + 3 = 5$; 2 added to 3 produces 5.

$-$ Sign of Subtraction, or *minus;* $6 - 4 = 2$; 4 subtracted from 6 leaves 2.

$\times$ Sign of Multiplication. $6 \times 3 = 18$; 6 multiplied by 3 produces 18. 3 is called the *multiplier*, 6 the *multiplicand*, and 18 the *product*.

$\div$ Sign of Division. $35 \div 7 = 5$. 35 divided by 7 gives 5. 35 is called the *dividend*, 7 the *divisor*, and 5 the *quotient*.

A horizontal stroke is sometimes used as the sign of Division.

In this case the number to be divided (*dividend*) is placed above, and the number which divides (*divisor*) below; thus, $\frac{35}{7} = 5$.

## ON FRACTIONS.

1. A Fraction is one or more parts of a whole number, and is produced by the division of a whole into any number of parts, and taking away one or more of them.

2. The figure denoting the number of parts into which the whole is divided is called the *denominator*, whilst the one expressing the number of these parts of which the fraction is composed, is called the *numerator*. Thus, in the fraction $\frac{4}{9}$, 4 is the numerator, and 9 the denominator.

3. There are, properly speaking, only two sorts of fractions, viz., *proper* and *improper*. A proper fraction is one in which the numerator is *less* than the denominator, as, $\frac{5}{8}$, $\frac{3}{4}$. An improper fraction is one in which the numerator is *greater* than the denominator, as $\frac{8}{5}$, $\frac{9}{4}$, $\frac{3}{2}$. When a whole number stands before a proper fraction, thus, $1\frac{5}{8}$ (one and five-eighths), it is called a *mixed* fraction.

## REDUCTION OF FRACTIONS.

4. An improper fraction may be reduced either to a whole number or to a mixed fraction, by dividing the numerator by the denominator, thus—

$$\frac{27}{3} = 9; \quad \frac{25}{9} = 2\frac{7}{9}$$

To reduce a mixed to an improper fraction, multiply the whole number by the denominator, and add the numerator to the product, which gives a new numerator, whilst the denominator remains the same; thus,

$$1\frac{1}{3} = \frac{4}{3}; \; 2\frac{3}{7} = \frac{17}{7}$$

### COMPARISON OF THE RELATIVE VALUES OF FRACTIONS.

5. In order to compare two fractions, place them side by side, and multiply the numerator of each fraction with the denominator of the other; thus,

$$3 \times 2 = 16 \qquad \frac{2}{3} \qquad \frac{7}{8} \qquad 3 \times 7 = 21$$

From this we see that $\frac{7}{8}$ is greater than $\frac{2}{3}$, because the number 21 stands by the fraction $\frac{7}{8}$, whilst only 16 is found by $\frac{2}{3}$. If the numerator and denominator of $\frac{7}{8}$ be multiplied by 3, the denominator of the other fraction, the result will be $\frac{21}{24}$; and $\frac{2}{3}$, when likewise multiplied by 8, the denominator of the other fraction, will give only $\frac{16}{24}$; thus, $\frac{7}{8}$ is greater than $\frac{2}{3}$ by $\frac{5}{24}$.

### TO REDUCE A FRACTION TO ITS LOWEST TERMS.

6. We have seen above, that the value of a fraction is not altered by *multiplying* the numerator and denominator by the same number. Similarly the value is not changed by *dividing* both numerator and denominator by the same number. It often adds much to the simplicity of an operation to have the fraction as small as possible; thus

$$\frac{24}{36} = \frac{2}{3}.$$

The numerator and denominator of this fraction can both be divided by 12, because 24 is made up of 2 multiplied by 12, or $2 \times 12 = 24$. Similarly 36 is produced by multiplying 3 and 12 together, or $3 \times 12 = 36$.

When, however, either the numerator or denominator is an uncompounded or *prime* number, the fraction cannot be reduced; thus, $\frac{23}{36}$ is in its simplest form, because 23 is a prime number.

If the numerator and denominator be both compound, but the

numbers of which each are compounded do not occur in, or are not common to both, the fraction cannot be reduced; thus,

$$\frac{25}{36}=\frac{5\times 5}{3\times 12}; \qquad \frac{14}{15}=\frac{2\times 7}{3\times 5}$$

When a fraction can only be reduced by an unequal number above 11, the rule given above is not so easy of application, as the numbers of which the numerator and denominator are compounded are not generally apparent at first sight; for instance, $\frac{1501}{1817}$ cannot be reduced by any number under 12, and it is difficult to ascertain by inspection whether a greater number will reduce it. This number may however be found by dividing the denominator by the numerator, then the numerator by the remainder, proceeding in the same manner, always dividing the previous divisor by the last remainder. When the operation is finished, the last divisor is the number which will reduce the fraction.

```
1501) 1817 (1
      1501
      ----
       316) 1501 (4
            1264
            ----
             237) 316 (1
                  237
                  ---
                   79) 237 (3
                       237
                       ---
                       ...
```

$$\frac{1501}{1817} \div 79 = \frac{19}{23}$$

From this we see that the numerator and denominator of $\frac{1501}{1817}$ are both divisible without remainder by 79.

REMARKS ON THE DIVISIBILITY OF NUMBERS.

If the last figure of a number is divisible by 2, so is the number itself. If the last two figures are divisible by 4, the number is also. If the last three figures are divisible by 8, so is the number itself. Every number ending in 0 can be divided by 2, 5, or 10; if it ends in 00, 4 will divide it; and if in 000, it can be divided by 8. If the sum of the figures of a number be divisible by 3 or 9, the number itself can be divided by 3 or 9. If the number ends in 5 it can be divided by 5.

### ADDITION.

7. In adding two or more fractions together, if the denominators are alike, add the numerators, and place the denominator under the sum so found; thus,

$$\frac{2}{13}+\frac{6}{13}=\frac{2+6}{13}=\frac{8}{13}; \qquad \frac{3}{8}+\frac{5}{8}=\frac{3+5}{8}=\frac{8}{8}, \text{ or } 1.$$

8. On the other hand, if the denominators are different, place both fractions side by side, and multiply the denominator of each fraction with the numerator of the other fraction. Add both these products, which gives the new numerator; and the two denominators multiplied together gives the new denominator.

$$\frac{2}{5}+\frac{3}{7}=\frac{(5\times3)+(7\times2)}{5\times7}=\frac{15+14}{35}=\frac{29}{35}$$

$$\frac{9}{14}+\frac{8}{9}=\frac{(14\times8)+(9\times9)}{14\times9}=\frac{112+81}{126}=\frac{193}{126}=1\tfrac{67}{126}$$

### SUBTRACTION.

9. In subtracting one fraction from another it must (as in Addition) be first ascertained if the denominators be alike. If so subtract the lesser from the greater, which gives the numerator. The denominator remains the same; thus,

$$\frac{7}{8}-\frac{5}{8}=\frac{2}{8}, \text{ or } \frac{1}{4}.$$

On the other hand, if the denominators are not alike, multiply (as in Addition) the numerator of each fraction by the denominator of the other fraction; and the one by which is found the greater product (see page 325 (5)) is the greater of the two. The lesser product is now subtracted from the greater, which gives the new numerator, whilst the new denominator is found by multiplying the two denominators together; thus,

(1.) $3\times3=9 \qquad \frac{3}{4}-\frac{2}{3} \qquad 4\times2=8$

$$9-8=1 \qquad \frac{1}{12}$$

$$4\times3=12$$

(2.) $7\times 8=56 \qquad \frac{7}{9}-\frac{5}{8} \qquad 9\times 5=45$

$$56-45=11 \qquad \frac{11}{72}$$
$$9\times 8=72$$

MULTIPLICATION.

10. If a fraction is to be multiplied by a whole number, the numerator only must be multiplied; thus,

$$\frac{3}{4}\times 2=\frac{3\times 2}{4}=\frac{6}{4}\text{ or }1\tfrac{1}{2}, \qquad \frac{3}{8}\times 3=\frac{3\times 3}{8}=\frac{9}{8}=1\tfrac{1}{8}$$

11. If one fraction is to be multiplied by another, multiply the two numerators and also the two denominators together; thus,

$$\frac{3}{8}\times\frac{4}{7}=\frac{3\times 4}{8\times 7}=\frac{12}{56}\text{ or }\frac{3}{14}$$

12. Mixed fractions must first be reduced to an improper form.

$$1\tfrac{3}{4}\times 2\tfrac{3}{7}=\frac{7}{4}\times\frac{17}{7}=\frac{119}{28}\text{ or }4\tfrac{1}{4}$$

DIVISION.

13. If it be required to divide a proper or an improper fraction by a whole number, divide the numerator by the number (if it will divide without a remainder), and the quotient is the new numerator, the denominator remaining the same; thus,

$$\frac{12}{13}\div 6=\frac{2}{13}. \qquad \frac{16}{21}\div 8=\frac{2}{21}$$

14. If, however, the numerator of the fraction is not divisible by the whole number or divisor, then multiply the denominator of the fraction by the divisor; thus

$$\frac{3}{4}\div 7=\frac{3}{4\times 7}=\frac{3}{28} \qquad \frac{4}{5}\div 8=\frac{4}{5\times 8}=\frac{4}{40}\text{ or }\frac{1}{10}$$

15. When a mixed fraction is to be divided by a whole number, it must first be brought into an improper form, and then treated as in (1) and (2); thus

$$18\tfrac{1}{2}\div 8=\frac{37}{2}\div 8=\frac{37}{8\times 2}=\frac{37}{16}=2\tfrac{5}{16}$$

16. *Observation.*—Beginners who find it difficult to recollect the various rules, may make use of the following summary, which is the shortest and easiest method of performing division of fractions of any kind. In calculating screw threads, multiplication and division only are used.

17. When a fraction, either proper, improper, or mixed, is to be divided by a whole number, or by another fraction, which may likewise be either proper, improper, or mixed, set the dividend on the left and the divisor on the right-hand side. If either the dividend or the divisor be a whole number, place under it the figure 1, or imagine it to be so placed; then multiply the numerator and the denominator of the dividend with the denominator and the numerator of the other fraction; thus,

| | | |
|---|---|---|
| $\frac{3}{4}$ divided by $\frac{1}{2}$ | | $\frac{3}{4} \div \frac{1}{2} = \frac{6}{4}$ or $1\frac{1}{2}$ |
| $2\frac{3}{7}$ | .... $1\frac{5}{8}$ | $\frac{17}{7} \div \frac{13}{8} = \frac{136}{91}$ or $1\frac{45}{91}$ |
| $4\frac{1}{3}$ | .... $\frac{3}{4}$ | $\frac{13}{3} \div \frac{3}{4} = \frac{52}{9}$ or $5\frac{7}{9}$ |
| $\frac{7}{8}$ | .... 2 | $\frac{7}{8} \div 2 = \frac{7}{16}$ |
| 4 | .... $\frac{3}{4}$ | $4 \div \frac{3}{4} = \frac{16}{3}$ or $5\frac{1}{3}$ |

### THE RULE OF THREE.

18. The Rule of Three enables us to find a fourth proportional to any three given numbers.

The mode of proceeding is as follows:—Multiply the second term by the third, and divide the product by the first term, which will give the fourth term sought.

The first term is used as a divisor, whilst the second and third are multipliers.

19. The terms must be placed in the following manner:—The first must be of the same denomination or kind as the third; for instance, if the third term be in inches, the first must be so likewise. The second term must be similar to the fourth term sought. Thus, in 3 inches, 9 threads are contained; how many in one inch?

| Inches. | | Threads. | | Inch. |
|---|---|---|---|---|
| 3 | : | 9 | :: | 1 |

3) 9 (3
9
..
3 threads in 1 inch.

20. When a 0 occurs at the end of two or more of the terms, the first and either of the others may be struck out of each, thus simplifying the operation. If two of the terms can be reduced by any number, it may be done without affecting the result; thus,

| Inches. | | Threads. | | Inch. |
|---|---|---|---|---|
| 20 | : | 40 | :: | 1 |

2) 4 (2
4
..
2 threads to one inch.

PROOF.

| Inch. | | Threads. | | Inches. |
|---|---|---|---|---|
| 1 | : | 2 | :: | 20 |

$$\begin{array}{r} 2 \\ 20 \\ \hline 40 \end{array}$$

40 threads per inch.

## RULE OF THREE WITH FRACTIONS.

21. The three terms are placed as before, the mixed fractions having been first reduced to an improper form. Transfer the denominator of the 1st term (dividing term) to the 2d and 3d terms (multiplying terms), and the denominator of the 2d and 3d terms to the 1st. Then reduce any two or more of the numerators or denominators by any number which will leave no remainder. Then multiply the 2d and 3d terms together and divide by the 1st. (See articles, Multiplication and Division.)

EXAMPLE 1.

| Inches. | | Threads. | | Inch. |
|---|---|---|---|---|
| $12\frac{1}{2}$ | : | $32\frac{1}{2}$ | :: | 1 |
| $\frac{25}{2}$ | : | $\frac{65}{2}$ | :: | 1 |
| | | 13 | :: | 1 |

5)13
$2\frac{3}{5}$

$2\frac{3}{5}$ threads per inch.

### EXAMPLE 2.

| Inches. | | Threads. | | Inch. |
|---|---|---|---|---|
| 20 | : | $39\frac{3}{4}$ | :: | 1 |
| 20 | : | 159 | :: | 1 |
| 4 | | 4 | | |
| 80 | : | 159 | :: | 1 |

80)159($1\frac{79}{80}$
80
79

$1\frac{79}{80}$ threads per inch.

### PROOF.

| Inch. | | Threads. | | Inches. |
|---|---|---|---|---|
| 1 | : | $1\frac{79}{80}$ | :: | 20 |
| 1 | : | 159 | :: | 20 |
| | | 80 | | |
| 80 | : | 159 | :: | 20 |
| | | 80 | | |
| 4 | : | 159 | :: | 1 |

4)159
$39\frac{3}{4}$

$39\frac{3}{4}$ threads in 20 inches.

## CHAPTER XXIX.

### EXPLANATION OF THE METHODS OF CALCULATING SCREW THREADS.

1. Cutting a screw in the lathe is only a common mechanical operation, of which the most important part is the selection of the proper change wheels. The wheels may be placed in two ways—

(1) With two change wheels, Plate 29, Fig. II. The middle wheel serves only to connect the two other wheels.

(2) With four change wheels, Plate 29, Fig. III.

The distance between the mandrel and the leading screw of a lathe does not generally admit of cutting a screw of more than 10 threads to the inch, with two wheels only, as the wheel on the leading screw would be too large, and that on the mandrel too small.

In the same way for cutting coarse pitched screws, such as ½ a turn to the inch, the second method is generally used, or else the wheel on the leading screw would be too small, and that on the mandrel too large. Thus the second method is employed for cutting screws of coarser pitch than ½ a thread, and finer than 10 threads to the inch, and the first method for screws of a pitch intermediate between ½ a thread and 10 threads to the inch.

In cases where a screw of an equal pitch, such as $1\frac{79}{80}$ threads to the inch, is required to be cut, which does sometimes happen when a screw has to be made exactly similar to a pattern, the second method must be used, although the pitch is intermediate between ½ a thread and 10 threads to the inch. In this instance an error is very likely to arise if the pitch of the screw be not measured on a long length, $1\frac{79}{80}$ threads being hardly distinguishable from two threads in a short distance. According to the Rule of Three (see Chapter XXVIII., Par. 21), 20 inches of a screw of this kind contain 39¾ threads.

Thus it must be observed, that in measuring a screw, to ascer-

tain its pitch, the greatest possible length should be made use of, although more exact fractions than $\frac{1}{4}$, $\frac{1}{8}$, or $\frac{3}{4}$ cannot be estimated with accuracy.

Figure I. represents a screw having

| | | | |
|---|---|---|---|
| 12 | threads in | 6 | inches |
| $12\frac{1}{4}$ | " | $6\frac{1}{8}$ | " |
| $12\frac{1}{2}$ | " | $6\frac{1}{4}$ | " |
| $12\frac{3}{4}$ | " | $6\frac{3}{8}$ | " |
| 13 | " | $6\frac{1}{2}$ | " |

## EXPLANATION OF THE FIRST METHOD WITH TWO WHEELS.

2. In order to ascertain the wheels required to cut a particular screw, we must first know the pitch of the leading screw of the lathe; for as often as the pitch of the leading screw is contained in that of the required screw, so often must the number of teeth in the wheel on the mandrel be contained in the number in that on the leading screw.

Divide the number of teeth per inch in the screw to be cut by the number per inch in the leading screw. The quotient gives the proportion which must exist between the number of teeth in the wheel on the leading screw and the number in that on the mandrel.

*Example* 1.—It is required to cut a screw *a*, Plate 29, Fig. II., of 4 threads to the inch. The leading screw *b* has 2 threads to the inch. The wheel on the mandrel is denoted by *c*, and that on the leading screw by *d*.

$$\frac{d}{c}=\frac{a}{b}$$

*Explanation of the formula.*—The number of teeth in wheel *d* on the leading screw, divided by the number in the wheel *c* on the mandrel, must be equal to the number of teeth per inch in the screw to be cut divided by the number per inch in the leading screw. *Remark.*—If the quotient be a whole number, a unite must be placed under it.

$$\begin{array}{l} a=4 \\ b=2 \end{array} \quad \frac{a}{b}=\frac{4}{2}=\frac{2}{1} \text{ the proportional number.}$$

$$\left.\frac{2}{1}\right\} 40 \begin{array}{l} =80\ d \text{ (numerator).} \\ =\overline{40}\ c \text{ (denominator).} \end{array}$$

3. The number of teeth per inch in the required screw $a$ must be divided by the number per inch in the leading screw $b$. 4 divided by 2 gives 2, or $\frac{2}{1}$. The number 2 (numerator) represents the wheel $d$ on the leading screw, and the number 1 (denominator) represents the wheel $c$ on the mandrel. The numerator and denominator (2 and 1) are now to be multiplied by any arbitrary number; 40 is the one here chosen, which shows us that the wheel $d$ (N)* on the leading screw must contain 80 teeth, and the wheel $c$ (D)† on the mandrel will be one of 40 teeth.

*Proof.*

$$\frac{d}{c} \times b = a$$

*Explanation of the formula.*—The number of teeth in wheel $d$ on the leading screw divided by the number in the wheel $c$ on the mandrel, and the product multiplied by the number of teeth per inch in the leading screw $b$, is equal to the number of teeth per inch in the screw $a$ required to be cut.

$$\begin{array}{lll} a = 4 & \text{threads} & \\ b = 2 & \ldots & \frac{8}{4} = 2 \\ c = 40 & \text{teeth} & \\ d = 80 & \ldots & 2 \times 2\,b = 4\,a \end{array}$$

We have already observed that the number of teeth in wheel $d$ (N) on the leading screw divided by the number in wheel $c$ (D) on the mandrel must be equal to the number of threads per inch in the required screw $a$ divided by the number per inch in the leading screw $b$. Therefore the driven screw $a$ and the driven wheel $d$ on the leading screw must represent the two numerators, whilst the driving leading screw $b$ and the driving wheel $c$ on the mandrel represent the two denominators.

4. The wheel of 40 teeth $c$ on the mandrel makes 2 revolutions whilst the wheel of 80 teeth $d$ on the leading screw makes 1 revolution. By this motion the tool will have been advanced through the space of half an inch, marking upon the screw to be cut (which makes 2 revolutions) 2 equal divisions. But as the leading screw must make 2 revolutions in order to advance the tool 1 inch, the remaining half inch is, as before, divided into 2 other equal parts.

---

* Numerator. † Denominator.

Two half inches being both divided into 2 parts makes 4 divisions in one inch, which is the number per inch in the required screw *a*.

*Example* 2.—It is required to cut a screw of $1\frac{3}{4}$ threads to the inch, the leading screw being the same as in previous example.

$$\frac{1\frac{3}{4}}{\frac{7}{4} \div 2 = \frac{7}{8}} \text{ the proportional number.}$$

$$\left.\begin{matrix}\frac{7}{8}\end{matrix}\right\} \times 10 \begin{matrix}=70d.\\=80c.\end{matrix}$$

#### EXPLANATION OF THE SECOND METHOD WITH FOUR WHEELS.

5. The use of 4 wheels has the advantage of allowing the arbitrary selection of one pair of wheels, the other pair being found by calculation. The principle is, however, the same as when using two wheels, except that the proportion, instead of being between a pair of wheels is between two pair of wheels.

The quotients of each pair of wheels when multiplied together will be equal to the proportion between the leading screw *b* and the required screw *a*.

*Example* 1.—It is required to cut a screw *a* of 18 threads to the inch. The leading screw *b* has 2 threads to the inch.

*c* represents, in Fig. III., Plate 29, the driving mandrel pinion, *d* the driven stud wheel, *e* the driving stud pinion, *f* the driven leading screw wheel. Then

$$\frac{d}{c} \times \frac{f}{e} = \frac{a}{b}$$

*Explanation of the formula.*—The number of teeth in the driven stud-wheel *d* (N) divided by the number in the driving mandrel pinion *c* (D) and multiplied by the number of teeth in the driven screw wheel *f* (N) divided by the number in the driving stud pinion *e* (D), is equal to the number of threads per inch in the required screw *a* divided by the number per inch in the leading screw *b*.

As mentioned before, we may select a pair of toothed wheels, but the fraction which they form must be exactly observed, and as the required screw contains more threads per inch than the leading screw, it will be obvious that the wheels of the numerators must

be larger than those of the denominators. If, however, the required screw contain less threads per inch than the leading screw, the wheels of the denominators must be larger than those of the numerators.

Select, for instance, $\left.\begin{array}{l}60 \text{ numerator} \\ 40 \text{ denominator}\end{array}\right\} \text{or} = \frac{3}{2}$

The proportional number between the required screw and the leading screw would be as follows:

$$\frac{a}{b}\ \frac{18}{2} = 9 \text{ the proportional number.}$$

Consequently a whole number or a fraction must be found, which, multiplied with the chosen fraction $\frac{3}{2}$, produces the proportional number 9.

As the proof of multiplication is division, and proof of division multiplication, the proportional number 9 is simply to be divided by the fraction $\frac{3}{2}$.

$$9 \div \frac{3}{2} = \frac{18}{3}, \text{ or } 6.$$

As the factor of the two-toothed wheels found is a whole number, a 1 may be put in place of the denominator, as $\frac{6}{1}$, and multiply the numerator 6 and the denominator 1 by any arbitrary number; for instance,

$$20 \times \left\{\begin{array}{l} 6 = 120 \text{ the driven wheel } f \text{ (N) on leading screw.} \\ 1 = \ \ 20 \text{ the driving wheel } e \text{ (D) on stud.}\end{array}\right.$$

The two pair of wheels may either be placed on a mandrel, or on the leading screw. It is, however, to be observed, that the pair containing the largest wheel is placed on the leading screw. If this be not done, the large wheel *d* on the stud representing the numerator would not allow the wheels *e* and *f* to work together, because the large wheel on the stud would touch the leading screw.

PROOF OF THE EXAMPLE.

$$\frac{d}{c} \times \frac{f}{e} \times b = a$$

*Explanation of the formula.*—The number of teeth in wheel $d$ divided by that in $c$, and multiplied by the number of teeth in $f$ divided by that in $e$, and this product again multiplied by the number of threads per inch in the leading screw $b$, is equal to the number per inch in required screw $a$.

$$\frac{d}{c}\frac{60}{40} = \frac{3}{2} \qquad \frac{f}{e}\;\frac{120}{20} = 6 \qquad 6 \times \frac{3}{2} = \frac{18}{2} = 9$$

$$9 \times b = 9 \times 2 = 18 = a$$

6. Whilst the wheel $f$ on the leading screw of 120 teeth (N) makes one revolution, the wheel $e$ on the stud of 20 teeth (D) makes 6 revolutions. And whilst the wheel $d$ on the stud of 60 teeth (N) makes 1 revolution, the wheel $c$ on the mandrel of 40 teeth (D) makes $\frac{3}{2}$, or $1\frac{1}{2}$ revolutions. But as the wheels $e$ and $d$ on the stud are coupled together, the wheel $c$ must make $6 \times 1\frac{1}{2} = 9$ revolutions. The pitch of the leading screw being $\frac{1}{2}$ an inch, it pushes the tool that distance forward during each revolution, marking 9 equal divisions upon the screw to be cut. As, however, the leading screw must make two revolutions to advance the tool through the space of 1 inch, the remaining half inch is likewise divided into 9 other equal parts, which gives a screw of the pitch required, viz., 18 threads to the inch.

It is required to cut a screw which shall contain $15\frac{3}{4}$ threads in 12 inches.

| Inches. | | Threads. | | Inch. |
|---|---|---|---|---|
| 12 | | | | |
| 4 | : | $15\frac{3}{4}$ | :: | 1 |
| 48 | : | 63 | :: | 1 |

$$48)\ 63\ (1\tfrac{15}{48}, \text{ or } 1\tfrac{5}{16} \text{ threads per inch.}$$
$$\underline{48}$$
$$15$$

Thus, according to the Rule of Three, the screw will contain $1\frac{5}{16}$ threads per inch

$$\frac{\overline{1\frac{5}{16}}}{} \qquad \frac{21}{16} \div 2 = \frac{21}{32} \text{ the proportional number.}$$

Assumed pair of change wheels $\left\{ \frac{30}{40} \frac{d}{c} \right.$ or $= \frac{3}{4}$;

$$\frac{21}{32} \div \frac{3}{4} = \frac{84}{96} \text{ or } = \frac{7}{8}; \quad \left.\frac{7}{8}\right\} \times 10 = \frac{70\ f}{80\ e}$$

In a length of 20 inches a screw contains $39\frac{3}{4}$ threads; how many are there to the inch?

| Inches. | | Threads. | | Inch. |
|---|---|---|---|---|
| 20 | : | $39\frac{3}{4}$ | :: | 1 |
| 4 | | | | |
| 80 | : | 159 | :: | 1 |

80) 159 ($1\frac{79}{80}$ threads per inch.

$$\frac{\overline{1\frac{79}{80}}}{} \qquad \frac{159}{80} \div 2 = \frac{159}{160} \text{ the proportional number.}$$

Assumed pair of change wheels $\left\{ \frac{30}{40} \frac{d}{c} \right.$ or $\frac{3}{4}$;

$$\frac{159}{160} \div \frac{3}{4} = \frac{636}{480.} \text{ or } = \frac{53}{40}. \quad \left.\frac{53}{40}\right\} \times 2 = \frac{106\ f.}{80\ e.}$$

## ANOTHER METHOD OF CALCULATING WITH FOUR WHEELS.

7. There is also another method of calculating when four wheels are employed, which is as follows:

Divide the number of teeth per inch in the required screw by the number per inch in the leading screw; change the quotient (if a whole number) into a fraction by placing a unit under it. If, however, the quotient should be a fraction, either proper or improper, it must be reduced to its lowest terms. The numerator and denominator must next each be resolved into two factors, as nearly equal as possible, or, in other words, two numbers must be found, which, when multiplied together, will form the numerator, and two others which, when multiplied together, will form the denominator. Should either the numerator or denominator be a

prime number, one of the factors will be 1, and the other the number itself.

8. The factors of the numerator are now to be multiplied by any two arbitrary numbers. The factors of the denominator are also to be multiplied by any two numbers whose product is equal to the product of the numbers by which the factors of the numerator were multiplied.

The two figures of the numerator represent the one, the wheel $f$ which is to be placed on the leading screw $b$, and the other the wheel $d$ on the stud. These wheels do not, however, work into each other. The two figures of the denominator give the number for the wheel $c$ on the mandrel, and for the wheel $e$ on the stud which wheels likewise do not work into each other.

*Observation.*—The two wheels $f$ and $d$ (numerators) are interchangeable with each other, as are also the wheels $c$ and $e$ (denominators).

1. *Example.*—It is required to cut a screw of $2\frac{1}{4}$ threads to the inch.

$$\frac{2\frac{1}{4}}{\frac{9}{4} \div 2 = \frac{9}{8}} \text{ the proportional number.}$$

The numerator resolved into 2 factors gives $3 \times 3 = 9$
. . . . . . . . . . $2 \times 4 = 8$

| | | | |
|---|---|---|---|
| 9 | $3 \times 20 = 60d$ | $3 \times 30 = 90f$ | $20 \times 30 = 600$ |
| 8 | $2 \times 60 = 120c$ | $4 \times 10 = 40e$ | $60 \times 10 = 600$ |

The common product of the assumed factors is 600, which is produced by multiplying together the assumed factors of the numerator ($20 \times 30 = 600$), and also by multiplying together the assumed factors of the denominator ($60 \times 10 = 600$).

| | | | | | |
|---|---|---|---|---|---|
| 20 multiplied by the factor | 3 | gives the wheel | $d$ | of 60 teeth | N |
| 30 . . . | 3 | . . | $f$ | . 90 . . | |
| 60 . . . | 2 | . . | $c$ | . 120 . . | D |
| 10 . . . | 4 | . . | $e$ | . 40 . . | |

*Example 2.*—It is required to cut a screw of $2\frac{1}{2}$ threads to the inch.

$$\frac{2\frac{1}{2}}{\frac{5}{2} \div 2 = \frac{5}{4}} \text{ the proportional number.}$$

| | | | |
|---|---|---|---|
| 5 | $1 \times 30 = 30 = d$ | $5 \times 20 = 100 = f$ | $30 \times 20 = 600$ |
| 4 | $2 \times 20 = 40 = c$ | $2 \times 30 = 60 = e$ | $20 \times 30 = 600$ |

*Example* 3.—It is required to cut a screw $4\frac{11}{16}$ threads to the inch.

$$\frac{4\frac{11}{16}}{\frac{75}{16}}\div 2=\frac{75}{32} \text{ the proportional number.}$$

| | | | |
|---|---|---|---|
| **75** | **15** × 5 = 75 *d* | **5** × 20 = 100 *f* | 5 × 20 = 100 |
| **32** | **4** × 10 = 40 *c* | **8** × 10 = 80 *e* | 10 × 10 = 100 |

There are some lathes in which the mandrel wheel cannot be changed, or, at all events, can only be increased or diminished to the extent of a few teeth, on account of the setting-up screw of the mandrel being in the way.

## WITH TWO WHEELS.

Divide, as before, the number of teeth per inch in the screw to be cut by the number per inch in the leading screw. The quotient gives the proportion between the number of teeth in the wheel on the mandrel and that on the leading screw.

It is required to cut a screw of 6 threads to the inch, the leading screw having 2 to the inch, and the fixed wheel *c* on the mandrel 30 teeth. How many teeth must there be in the wheel on the leading screw *d* ?

The proportion between the required and leading screw is $\frac{6}{2}=3$, or as 1 to 3, the proportional number.

The number of teeth in the driving wheel *c* on the mandrel must then be contained three times in the number in the wheel *d* on the leading screw.

$3\times 30=90$, number of teeth in wheel on leading screw.

## WITH FOUR WHEELS.

Find the proportional number as before, and if a wheel representing a numerator is to be calculated (it may be either the wheel *d* on the stud or the wheel *f* on the leading screw), multiply the number of teeth in the two wheels chosen (D) into each other, and also into the proportional number; divide the product by the number of teeth in the given wheel (N), and the quotient will be the number of teeth in the wheel sought (N).

*Example.*—It is required to cut a screw of 20 threads to the inch.

The wheel $c$ (D) on the mandrel has 40 teeth.
. . $d$ (N) . . stud . . 50 . .
. . $e$ (D) . . . . . . 15 . .
How many must the wheel $f$ on the leading screw have?

$$\frac{20}{2} = 10 \text{ the proportional number}$$

$$\frac{c \times e \times 10}{d} = f \qquad \frac{40 \times 15 \times 10}{50} = 120 \text{ teeth in wheel } f.$$

On the other hand, should a wheel representing a denominator be sought, divide the product of the number of teeth in the two wheels (N) by the product of the given (D) wheel and the proportional number.

$$\frac{d \times f}{10 \times e} = c \qquad \frac{50 \times 120}{10 \times 15} = 40 \text{ teeth in wheel } c.$$

There are some lathes in which the mandrel is connected with the leading screw by a triple arrangement, consisting of 3 pairs of wheels, or 3 fractions. The proportions in this position of the wheels remain the same as when 4 wheels are used, but with this difference, that the proportion of 2 pairs is contained by 3 pairs working together.

Therefore the quotients of the number of teeth in the 3 pairs of wheels must be multiplied together, and the product will be equal to the proportion between the required screw $a$ and the leading screw $b$.

*Example.*—It is required to cut a screw of 24 threads to the inch.

$$\frac{24}{2} = 12 \text{ the proportional number.}$$

In these cases we may choose any two pairs of change wheels.

$$\frac{40}{20} = 2 \quad \frac{90}{30} = 3 \quad 3 \times 2 = 6 \quad \text{product of the two pairs of wheels.}$$

We have here (as before) to find that number which, when multiplied by 6, shall produce the proportional number 12.

$$\frac{\text{Proportional number} \;.\;.\;.\;.\;.\;.\;.\;.\;.\; 12}{\text{Product of the two assumed pairs of wheels } 6} = 2$$

2 or $\frac{2}{1}$ multiplied by any arbitrary number, 30 for instance, gives

$$\left.\begin{matrix}2\\1\end{matrix}\right\}\times 30 \begin{matrix}=60\\=30\end{matrix}\Big\}\text{ the third pair.}$$

As already mentioned (par. 5, 6), the largest wheel must be on the leading screw. The arrangement then will be as follows:

The wheel

*f* of 90 teeth will be placed on the leading screw (N)
*e* " 30 . . . . . stud (D)
*d* " 40 . . . . . . .. (N)
*c* " 20 . . . . . mandrel (D)
" 60 second stud will work in wheel *e* (N)
" 30 . . . . . . . *f* (D)

*Example* 2.—It is required to cut a screw of ¾ of a thread to the inch.

$$2 : \frac{3}{4} = \frac{3}{8}\text{ the proportional number.}$$

Assumed pairs of change wheels.

$$\frac{30}{40}\text{ or }\frac{3}{4}\qquad \frac{7}{8}\times\frac{3}{4}=\frac{21}{32}$$

$$\frac{70}{80}\text{ or }\frac{7}{8}\qquad \frac{21}{32}:\frac{3}{8}=\frac{96}{168}\text{ or }\frac{12}{21}\text{ or }\frac{4}{7};\ \left.\frac{4}{7}\right\}\times 10\begin{matrix}=40\\=70\end{matrix}$$

It occasionally happens that the leading screw of the lathe is of an unequal pitch, but the same rules are to be used as in ordinary cases.

*Example.*—It is required to cut a screw of 2½ threads to the inch, the leading screw having $1\frac{47}{48}$ threads to the inch.

$$2\tfrac{1}{2} \div 1\tfrac{47}{48}$$

$$\frac{5}{2}\div\frac{95}{48}=\frac{240}{190}\text{ or }\frac{24}{19}\text{ the proportional number.}$$

Assumed pair of change wheels.

99 $$\frac{60\,d}{80\,c}\text{ or }\frac{3}{4}\quad \frac{3}{4}\div\frac{24}{19}=\frac{96}{57}\text{ or }\frac{32}{19};\ \left.\frac{32}{19}\right\}\times 5\begin{matrix}=160f\\=95e\end{matrix}$$

In order to cut a left-handed screw a carrier wheel is interposed between the mandrel and stud-wheels. This is however not taken into account in calculation, as it merely serves to reverse the motion.

TABLE SHOWING THE CHANGE WHEELS FOR SCREW-CUTTING TO BE USED IN A LATHE HAVING A LEADING SCREW OF TWO THREADS TO THE INCH.

| Number of threads per inch of screw *a*. | Number of teeth. | | Number of threads per inch of screw *a*. | Number of teeth. | | Number of threads per inch of screw *a*. | Number of teeth. | | Number of threads per inch of screw *a*. | Number of teeth. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mandrel pinion *c*. | Leading screw wheel *d*. | | Mandrel pinion *c*. | Leading screw wheel *d*. | | Mandrel pinion *c*. | Leading screw wheel *d*. | | Mandrel pinion *c*. | Stud wheel *d*. | Stud pinion *e*. | Leading screw wheel *f*. |
| ½ | 80 | 20 | 2½ | 60 | 75 | 5 | 30 | 75 | 10 | 60 | 75 | 20 | 80 |
| ⅝ | 80 | 25 | 2⅝ | 80 | 105 | 5¼ | 40 | 105 | 10½ | 50 | 70 | 20 | 75 |
| ¾ | 80 | 30 | 2¾ | 80 | 110 | 5½ | 20 | 55 | 11 | 60 | 55 | 20 | 120 |
| ⅞ | 80 | 35 | 2⅞ | 80 | 115 | 5¾ | 40 | 115 | 12 | 80 | 80 | 20 | 120 |
| 1 | 80 | 40 | 3 | 80 | 120 | 6 | 30 | 90 | 13 | 80 | 80 | 20 | 130 |
| 1⅛ | 80 | 45 | 3⅛ | 80 | 125 | 6¼ | 40 | 125 | 14 | 80 | 80 | 20 | 140 |
| 1¼ | 80 | 50 | 3¼ | 80 | 130 | 6½ | 20 | 65 | 15 | 80 | 80 | 20 | 150 |
| 1⅜ | 80 | 55 | 3⅜ | 80 | 135 | 6¾ | 40 | 135 | 16 | 60 | 80 | 20 | 120 |
| 1½ | 80 | 60 | 3½ | 80 | 140 | 7 | 20 | 70 | 17 | 45 | 85 | 20 | 90 |
| 1⅝ | 80 | 65 | 3⅝ | 80 | 145 | 7¼ | 40 | 145 | 18 | 40 | 60 | 20 | 120 |
| 1¾ | 80 | 70 | 3¾ | 80 | 150 | 7½ | 20 | 75 | 19 | 50 | 95 | 20 | 100 |
| 1⅞ | 80 | 75 | 3⅞ | 80 | 155 | 7¾ | 40 | 155 | 20 | 60 | 100 | 20 | 120 |
| 2 | 80 | 80 | 4 | 40 | 80 | 8 | 20 | 80 | | | | | |
| 2⅛ | 80 | 85 | 4¼ | 40 | 85 | 8½ | 20 | 85 | | | | | |
| 2¼ | 80 | 90 | 4½ | 40 | 90 | 9 | 20 | 90 | | | | | |
| 2⅜ | 80 | 95 | 4¾ | 40 | 95 | 9½ | 20 | 95 | | | | | |

## METHOD OF CALCULATING THE CHANGE WHEELS IN A WHEEL-CUTTING MACHINE.

9. Figure IV., Plate 29, shows the principal parts of a wheel-cutting machine. *a* represents the wheel to be cut, *b* the tangent wheel, *c* the wheel on the division-plate, *d* the wheel on the tangent screw-spindle, and *e* the number of revolutions of the division-plate.

The formula for the calculation of the change wheels is as follows:

$$\frac{c}{d} \times e = \frac{b}{a}$$

The number of teeth-wheel *c* on the division-plate divided by the number in wheel *d* on the tangent screw-spindle, and the quotient multiplied by the number of revolutions, will be equal to the number of teeth in the tangent wheel *b* divided by the number of teeth in the wheel to be cut *a*.

It is required to cut a wheel of 60 teeth. The tangent wheel *b* contains 180 teeth, and the division-plate *e* makes 2 revolutions.

The division-plate may be assumed to make ¼, ½, 1, 2, 3, 4, &c. revolutions, but the greater the number of teeth in the wheel to be cut, the fewer revolutions, there should be of the division-plate.

$$\frac{180}{3} = 60 \text{ the proportional number.}$$

The conditions of the case are here just contrary to screw-cutting. The number of teeth in the wheel to be cut represents the denominator, and the number in the tangent wheel the numerator. It follows, therefore, that the number of teeth in the driving-wheel *c* on the division-plate must represent the numerator, and the number in the driven-wheel *d* on the tangent screw-spindle, the denominator.

The number of teeth in the wheel to be cut, *a*, is contained 3 times in the number in the tangent wheel *b*; therefore the number in the wheel *c* on the division-plate, divided by the number in wheel *d* on the tangent screw-spindle, and multiplied by the number of revolutions, must also be equal to 3.

10. We have here (as in calculating change wheels for screw-

cutting when 4 are used) to find a number or fraction, which, when multiplied by 2, shall produce 3.

$$\left.\frac{3}{2}\right\}\times 10 \begin{matrix} =30c \\ =20d \end{matrix}$$

The proportional number 3 divided by 2 (revolutions) gives $\frac{3}{2}$ as a quotient. The numerator and denominator, multiplied by any arbitrary number, 10 for instance, gives $\frac{30}{20}$, which shows us that the driving-wheel $c$ of 30 teeth (N) must be on the division-plate spindle, and the driving-wheel $d$ of 20 teeth (D) on the tangent screw-spindle.

PROOF.

$$\frac{c\,30}{d\,20} \text{ or } \frac{3}{2}; \quad \frac{3}{2}\times 2=\frac{6}{2} \text{ or } 3$$

The number of teeth in the wheel $c$ on the division-plate spindle divided by the number in wheel $d$ on the tangent screw-spindle, and the quotient multiplied by 2 (the number of revolutions), gives the proportional number 3.

Whilst the wheel $c$ (N) of 30 teeth on the division-plate spindle makes 1 revolution, the wheel $d$ (D) of 20 teeth on the tangent screw-spindle makes $1\frac{1}{2}$. But as the division-plate must revolve twice, the wheel $d$ on the tangent screw-spindle will make $2\times 1\frac{1}{2}=3$ revolutions. Also, whilst the tangent screw makes 1 revolution, the tangent wheel will make $\frac{1}{180}$ of a revolution, as it is moved one tooth forward; but as the tangent screw makes 3 revolutions, the tangent wheel will have been moved through $\frac{3}{180}$ or $\frac{1}{60}$ of a revolution. Therefore, for each double revolution of the division-plate, the tangent wheel makes $\frac{1}{60}$ of a revolution; and as the wheel to be cut is to contain 60 teeth, the division-plate must make 60 double revolutions, and the tangent wheel $60\times\frac{1}{60}=\frac{60}{60}=1$ revolution, whilst the wheel is being cut.

TABLE SHOWING THE CHANGE WHEELS TO BE USED IN A WHEEL-CUTTING MACHINE HAVING A TANGENT WHEEL OF 180 TEETH.

| Number of teeth in wheel *a*. | Revolutions of the division plate *e*. | Number of teeth. On the division plate spindle *c*. | Number of teeth. On the tangent screw spindle *d*. | Number of teeth in wheel *a*. | Revolutions of the division plate *e*. | Number of teeth. On the division plate spindle *c*. | Number of teeth. On the tangent screw spindle *d*. | Number of teeth in wheel *a*. | Revolutions of the division plate *e*. | Number of teeth. On the division plate spindle *c*. | Number of teeth. On the tangent screw spindle *d*. | Number of teeth in wheel *a*. | Revolutions of the division plate *e*. | Number of teeth. On the division plate spindle *c*. | Number of teeth. On the tangent screw spindle *d*. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 4 | 90 | 20 | 33 | 4 | 60 | 44 | 56 | 2 | 45 | 28 | 79 | 2 | 90 | 79 |
| 11 | 4 | 90 | 22 | 34 | 4 | 45 | 34 | 57 | 2 | 60 | 38 | 80 | 2 | 45 | 40 |
| 12 | 4 | 75 | 20 | 35 | 4 | 36 | 28 | 58 | 2 | 90 | 58 | 81 | 2 | 60 | 54 |
| 13 | 4 | 90 | 26 | 36 | 4 | 50 | 40 | 59 | 2 | 90 | 59 | 82 | 2 | 45 | 41 |
| 14 | 4 | 90 | 28 | 37 | 4 | 45 | 37 | 60 | 2 | 30 | 20 | 83 | 2 | 90 | 83 |
| 15 | 4 | 60 | 20 | 38 | 4 | 45 | 38 | 61 | 2 | 90 | 61 | 84 | 2 | 45 | 42 |
| 16 | 4 | 45 | 16 | 39 | 4 | 60 | 52 | 62 | 2 | 45 | 31 | 85 | 2 | 36 | 34 |
| 17 | 4 | 90 | 34 | 40 | 2 | 45 | 20 | 63 | 2 | 40 | 28 | 86 | 2 | 45 | 43 |
| 18 | 4 | 50 | 20 | 41 | 2 | 90 | 41 | 64 | 2 | 45 | 32 | 87 | 2 | 60 | 58 |
| 19 | 4 | 90 | 38 | 42 | 2 | 60 | 28 | 65 | 2 | 36 | 26 | 88 | 2 | 45 | 44 |
| 20 | 4 | 45 | 20 | 43 | 2 | 90 | 43 | 66 | 2 | 60 | 44 | 89 | 2 | 90 | 89 |
| 21 | 4 | 90 | 42 | 44 | 2 | 45 | 32 | 67 | 2 | 90 | 67 | 90 | 2 | 90 | 90 |
| 22 | 4 | 90 | 44 | 45 | 2 | 40 | 20 | 68 | 2 | 45 | 34 | 91 | 2 | 90 | 91 |
| 23 | 4 | 90 | 46 | 46 | 2 | 90 | 46 | 69 | 2 | 60 | 46 | 92 | 2 | 90 | 92 |
| 24 | 4 | 30 | 16 | 47 | 2 | 90 | 47 | 70 | 2 | 54 | 42 | 93 | 2 | 60 | 62 |
| 25 | 4 | 45 | 25 | 48 | 2 | 75 | 40 | 71 | 2 | 90 | 71 | 94 | 2 | 45 | 47 |
| 26 | 4 | 90 | 52 | 49 | 2 | 90 | 49 | 72 | 2 | 30 | 24 | 95 | 2 | 36 | 38 |
| 27 | 4 | 40 | 24 | 50 | 2 | 54 | 30 | 73 | 2 | 90 | 73 | 96 | 2 | 45 | 48 |
| 28 | 4 | 45 | 28 | 51 | 2 | 60 | 34 | 74 | 2 | 45 | 37 | 97 | 2 | 90 | 97 |
| 29 | 4 | 90 | 58 | 52 | 2 | 45 | 26 | 75 | 2 | 24 | 20 | 98 | 2 | 45 | 49 |
| 30 | 4 | 60 | 40 | 53 | 2 | 90 | 53 | 76 | 2 | 45 | 38 | 99 | 2 | 40 | 44 |
| 31 | 4 | 90 | 52 | 54 | 2 | 50 | 30 | 77 | 2 | 90 | 77 | 100 | 2 | 45 | 50 |
| 32 | 4 | 90 | 64 | 55 | 2 | 36 | 22 | 78 | 2 | 60 | 52 | | | | |

# CHAPTER XXX.

## THE MANAGEMENT OF STEEL.

FORGING, hardening, and tempering of steel is an art very much admired, the agreeable exercise it affords to the mind, the beauty and utility of its use, often entice the young mechanic to try his skill, or rather to gain a little knowledge of the tools he uses; and it will be my endeavor to point out the way in as simple a manner as possible, which will enable the most inexperienced to gain a perfect knowledge in the hardening and tempering of the tools they use, likewise the qualification a tool should have to be considered a good-shaped tool; and it will not, I presume, prove uninteresting to the general reader. It is an art of long standing; but by whom or when it was first adopted I am not prepared to decide. In this place it claims notice on account of its contributing so essentially to the perfection of all other arts; and having had long experience in the art, and wrought among thousands of different mechanics, I have had an opportunity of seeing that such a work as the present is wanting among them; and being prevailed upon to write it, I have taken the advantage of a few leisure hours, not merely to write hearsay, but practical experience.

### ON THE FORGING OF STEEL.

Steel being one of the most valuable metals in general, and requiring great care in the forging, hardening, tempering, and annealing, and the management of it in general, I think, after having had nearly twenty years' good practice, and experience, and study combined, I am now able to give a little information to those who have not had so much to do with it as I have; and any thing that I here state is from my own practical experience; and by following the plans I shall here give, the artist will meet with every success. There are many people who, for the want of a little

useful knowledge on steel, refrain from making many a good tool, because they say it is sure to crack in hardening; but if the steel is good, and not been spoilt in forging the article, by following my plans they never need be afraid that it will be a waster. There are tons of the very best steel condemned as bad steel—at the same time it is the forging of it that has made it bad, through men not having a proper knowledge in the management of it; and those masters who study their own interest will only employ those men for the forging of steel on whom they can most depend. For I have seen plenty of the very best steel destroyed, and have even heard men remark to each other, "Make it well hot—it will work the easier," and I have felt what a sad thing it was to see men that knew better; yet they would destroy their employer's property. Therefore I say, as justice to the manufacturer and supplier of steel, it becomes masters to put those men only at the forging of steel on whom they can most depend.

In forging of cast-steel the fire must be regulated by the size of the work; and in heating the steel, when the flames begin to break out, beat the coals round the outside of the fire close together with the slice to prevent the heat from escaping. To save fuel, damp the coal, and throw water on the fire if it extend beyond its proper limits. To ascertain the heat of the steel, draw it out of the fire, and that often, for it requires to be well watched to heat the steel properly; and if not hot enough, thrust it quickly in again. Soft coke is even better than coal for the fire. The heat the steel receives is judged of by the eye; and care should be taken not to use a higher degree of heat than is absolutely necessary to effect the desired purpose, and to use as few heats as possible; too frequent and overheating steel abstracts the carbon, gradually reducing it to the state of forged iron again. It is an idea of many men, that so long as the steel does not fly to pieces when they strike it with the hammer, it is not too hot; but it is an erroneous idea, and easily proved when it comes to be hardened, and when it comes to be used; but it is an idea that many men will maintain, but it is only for the want of knowing better, and I hope that this will have the effect of altering their opinion. I can safely say that no man will ever injure the steel by being too careful how he takes his heats. Cast-steel may be welded by boiling sixteen parts of borax and one of sal ammoniac together over a slow fire for an

hour, and when cold to be ground into a powder. The steel must then be made as hot as it will conveniently bear, and the borax used as sand.

## ON THE HARDENING OF STEEL.

Now my object is to show the reader some of the chief causes of steel breaking in hardening, and likewise to give a few remedies to prevent these causes; and I am sure, from my own experience, that whoever tries them will find them correct. In the first place, I wish to apprise the reader that all bright steel requires a coating of some description before putting it in the water, more especially when the article runs large, or the sudden action of the water on the outside of the steel in most instances is sure to crack it. As a proof of this, take a piece of steel cut from a bar with the skin on, harden it as often as you please, and you will find that it is a very uncommon thing for that either to crack or break, if it is not made too hot; but take the same piece of steel, or another piece from the same bar, file or turn it bright, it is quite likely to break the first time it is hardened. As a proof that the skin on the steel prevents the water from acting so suddenly on the outside of the steel, in cooling it so much sooner than the middle, common turning-tools will always stand better, and keep a finer edge, if the tools are hardened from off the hammer with the skin on, to what they will if they are either filed or ground before hardening; that is, if the heat of the steel is regulated so as not to require tempering after being made hard, as the most useful hardness is produced by that degree of heat which is just sufficient to effect the purpose; for the hardness of steel depending upon the intimate combination of its carbon, therefore the heat which effects this is the best. But there are a number of tools used in the turnery that cannot be ground after hardening, therefore these must be fitted up with the file, and the necessary precautions used in hardening them; for not being able to grind them after they are hardened, owing to their peculiar shapes, it is a matter of importance that these should stand well, for were the edge to chip through being a little too hard, or the edge to rub off through being a little too soft, the tool must be softened and fitted up again, and in many instances the tool would be wholly useless, for the proper size of it would be

gone. Therefore, if extra care is to be taken with some tools, it is the like of tools that cannot be repaired. But all tools that can be ground after being hardened are the better for being hardened with the skin on the steel; and if the tool-smith understands his business, he knows the proper shape of the tools as well as the mechanic who is using them, and he will give very little grinding on the tools, and for water-cracks there will be none. In the hardening of steel, it demands a nicety of management which some artists are not often very anxious to display, as I shall here show, that some would not give themselves the trouble to do what they really know is requisite to do before they put the article in the fire, therefore they put it in and chance their luck. But luck has never been my motto—success is what I always aimed at; and it has always been my plan, if I never gained credit to take care I never lost any; and I hope this will act as a word of advice to many young men just starting in the world. Before putting any article in the fire it is necessary to examine its shape, as every article has a particular way in which it should go into the water; therefore, it is requisite to know, before it is put into the fire, which way it is to be put into the water when it is drawn from the fire; likewise the water has to be studied into which the article is put, and likewise the heat on the article before it is put in the water, and the position of it in putting it in the water. Water that is intended for hardening with should never be dead-cold; and the heat of the article, if the steel is good, should never exceed that of a low red heat; for if the water is dead-cold, and the steel a little too hot, there is as much risk of its breaking as there is by pouring boiling water into a glass bottle; for dead-cold water acting so sudden on the outside of the steel, the expansion of the middle is more than the outside can bear, so it causes the steel to break; therefore, to avoid such risk, get a quantity of lighted charcoal, or a bar of ignited iron, and put it in the water, just sufficient to take the chill off; in dipping any article in the water, if there is a stout part and a thin part, always let the stoutest part go in the water first, and as near the centre of the water as possible, so that there is an equal pressure of water surrounding it; by putting the stoutest part in the water foremost it causes the article to cool more equal, whereas if the thin part be put in the water foremost it is cold first, and the stout part having to contract

after the thin part is cold, the thin part cannot give, consequently it has to break. But this cannot always be done, as there are no means of getting the stoutest part of some articles in the water foremost; for instance, such an article as a feather-edge milling-cutter, and many other things which have their stoutest part in the centre,—these must be put in perpendicular, by putting a piece of strong wire through the hole in the centre, and putting it gently into the water; and instead of moving it backwards and forwards in the water, lift it up and down, so that fresh water pass through the centre every time it is lifted up and down, and the deeper the tank the better it is; but in lifting it up it must not be allowed to come above the water, or it will be sure to crack; the outside edges of such articles being much thinner than the middle, they are cold sooner, so that the middle is wanted cold as quick as possible with the outside edges; and were it drawn backwards and forwards in the water, the water being warm in the hole in the centre, it is longer in cooling, the outer edge being dead-cold, and the middle of the cutter contracting, the outside is too cold to give, so it ends in the article breaking; so, by a little attention to the above, they are accomplished without breaking them. The wire that is used to bear the cutter while dipping it in the water must have three forks at the end for the cutter to lie upon, so that there is no obstruction to the water passing freely through the hole; with the inexperienced it is, just heat it, and put it in the water, without regard to any thing which causes such losses to the employer, and then it is condemned as bad steel; but it is not all bad steel that breaks, for the very best steel will break, if it is not properly managed.

I speak from experience that the shape of different articles has to be studied; for instance, take such an article as an eccentric collar in the way of example, which shall be one and a half inches thick on one side, and a quarter of an inch on the other, having a two-inch hole in it for the shaft; in hardening this it is most certain to break in the weak side, for one side being so thin, it is cold almost instantly, and the stout side contracting after the other is cold, it pulls it asunder. By taking a little trouble all this risk is avoided. Before such an article as the above be put in the fire, fit a piece of iron round the thin part, so that it is made up to the thickness of the stout part, or a little thicker, and bind it on with

a piece of binding wire, and coat it with potash, and I will guarantee that it hardens without breaking, because one part then is cold as soon as the other. There are various things that steel can be coated with, such as soft soap, black lead, or plumbers' size; but in hardening in a common fire, or a furnace, the prussiate of potash is the best; but in hardening in lead, soft soap, black lead, or plumbers' size answers exceedingly well. In coating of steel, you first get the article just red, draw it from the fire, having the potash already powdered up fine, and in a box with small holes in the lid, similar to a grater; shake the box till there is a coat all over the articles, put it in the fire again till it gets to the desired heat, and it is then ready to put into the water, except in very large articles, where there is a great body of steel. It is requisite then to draw it from the fire a second time, and give it another sprinkle of potash, so as to give it a thicker coat. By binding a little binding wire about it, it assists to make the potash cling more firmly to it. There are many things that require to be hardened, where the substance of the steel is so great that it is necessary to bore holes about it in different places to make it cool more equally; in very large cutters some are apt to have the hole where the spindle passes through too small, so that large and small cutters may fit the same spindle; but the larger the cutter the larger the hole should be; or otherwise bore a few holes round the middle hole, so that the substance of the steel is reduced, and it will not interfere with the strength of the cutter, and there is then no danger attending it in hardening. But if it happen that any article that has to be hardened has any holes about it near to the very edge, it is then requisite to stop these holes up with a piece of loom, and it will prevent the hole breaking out. Any size cutters, bushes, gauges, rings, or collars, or articles of any description, may be hardened without breaking by following the rules I lay down. Sometimes a steel ring or a cutter is required to have one thin edge; these must be put in the water with the stoutest part downwards, and if the edge is very thin, it must not be put in the water too suddenly. In very large round steel it is sometimes necessary to bore a hole through the centre to allow the water to pass through, and even then it will break asunder if it be drawn backwards and forwards in the tank; this should always be lifted up and down in the water to allow fresh water to pass through the

hole, unless when it is under the water; if it be turned on to its side. it can then be drawn backwards and forwards with the same result. It sometimes happens that there is a fracture in the steel before it is hardened: this can be detected when the article is in the fire, and at a low heat. This fracture is sometimes found in the steel as it comes from the manufacturer, and very often caused in the forging by excessive heating, and oftentimes the hardener gets blamed for faults which belong to other men. If there is a crack in the steel when it is just red, it can be detected, but hardening will not mend it; it may be useful to some to know, that if a piece of binding wire be bound round any article, and a piece of loom wrapped round the wire, the wire merely to keep the loom from falling off, and after drying the loom, the article may be put in the fire and heated all over, and when sufficiently hot it may be put into the water, and the part that has the loom round it will remain soft, because the water cannot penetrate through the loom quick enough to harden the steel. If the loom be on the middle, the ends only will be hard; but if the loom be on the ends, the middle will be hard, and the ends soft, and the mechanic will find this plan very useful in many cases. In hardening of steel, the more the water is hardened in the better it is for the purpose; but according as it wastes, fresh water must be added to it, and as it is necessary to clean the tank out occasionally, before using fresh water, it is best to make it well hot by putting a bar of ignited iron into it, and let it get cold again before using it; for when dead-cold water is used, there is always a risk of the steel cracking.

As there is such a variety of different shaped articles, to speak separately of every one would require a whole volume; therefore I think the necessity for a much further minuteness of detail will be removed by a little observation and experience. My mode of treatment of steel in some cases may be classed, perhaps, among those inventions which some are apt to wonder they never thought of, and, like many other things, very simple after they are made known, the simplicity of which raises their value; but simple as they may appear to some, they are facts of great importance in the management of steel. By applying aquafortis to the surface of steel previously brightened, it immediately produces a black spot; if applied to iron the metal remains clean, but looking a little dull where the acid touched it. By this test iron may be

known from steel, as the smallest vein of either will be distinguished by its peculiar sign. There are many large things broken by taking them out of the water before they are thoroughly cold, and some people are of the opinion that it is the action of the air on the steel which causes it to break; but my opinion is, that the middle of the steel not being thoroughly cold, and the outside of the steel being quite cold, the instant the steel is lifted from the water the middle begins to expand, and the outside being quite hard, the expansion is more than the outside can bear, so it causes it to break; but be this as it may, it is a real fact, that if a large body of steel be taken out of the water before it is thoroughly cold, in nine cases out of ten it is sure to break. If a large piece of iron is heated and put in the water, and kept under the water a considerable time, after the outside of the iron is black, draw it out of the water; in a few seconds the heat from the middle of the iron will turn the outside to a red heat again. Water acts on steel in a similar manner. When first the article is put into the water, the water begins to act on the outside of the steel, cooling it gradually towards the middle; and if taken from the water before it is quite cold, the heat from the middle begins to act on the outside of the steel in a contrary way to the water, by straining the outside of the steel more than it can bear; and in most instances I have noticed, when I have been trying experiments, that as soon as the water dries on the steel, it cracks, and the larger the steel the greater the risk, so it is important that it should be quite cold, before it is taken out of the water, if the article be in any way large.

It is not requisite that the article should lie in the water till the water is dead-cold, for in some instances the article is wanted for use as soon as possibly it can be had; in such cases, if the article is not too large to go into a handbowl, put the bowl under the water in the tank, and place the article in the bowl, lift the bowl and the article out together, with the water covering the article in the bowl, and then sink the bowl with the article still in it into another tank of dead-cold water, or under a tap, with cold water running on it, and it will in a short time be ready to lift out. But if the article is too large to go into a bowl, put it in a bucket and act as I have stated, and it will then come out safe without a crack, and it will not crack after it is out, as hundreds of things

break, by lifting them out before they are cold. I have had very large things to harden that have taken weeks to make, and had I not taken these precautions, which some are apt to think too much trouble, I should have had many a waster; but trouble I never think about, success has always been my aim, and experience teaches me to give this little information to those that have not had the opportunity of having the experience I have had. There are many things cracked in hardening, by heating the article all over, and then dipping it in the water half-way. Such things as taps, drifts, and numerous other articles, should always be hardened all over, if they are heated all over, and then if one part is required softer than the other, it is best to soften it after, or otherwise not to heat it farther than where it is required hard; for if they are heated all over, and you in dipping them in the water stop at any particular part, and hold it still in that spot, if the water is quite cold, in nine cases out of ten there will be a crack at the very spot which is level with the top of the water, and in some cases it will break clean asunder at that particular spot, as straight nearly as if it were sawn through with a saw. But these cracks may be prevented in a very great measure by simply putting the water in motion, or moving the article quickly about when it is in the water as far as it is required hard; the water is then prevented from acting so evenly round it; or otherwise, if a few coils of binding-wire be bound round the part intended to be level with the top of the water, and a coat of potash put about the wire, there will be no crack there, as it prevents the water from acting so suddenly on it. But in many things where the heat that is on the article is wanted to temper the part that is dipped in the water, such as chisels, drills, and the like articles; these things, when they are dipped to the depth required to harden them, should always be moved quickly about in the water, and it will prevent many a drill screwing off in that particular spot, and prevent many a chisel breaking. I have no doubt that many readers of this book have noticed when they have been chipping, that their chisels have broken clean off, about an inch from the edge, with a very light blow from the hammer, and the cause of that is in a great number of instances, by holding the chisel still in the water when hardening it; for the water cooling it across in a straight line causes the hardened part to tear from the other, yet

not sufficient to show till such time it is struck with the hammer, and then it drops off, and if the break be examined it can be seen that the water did it. But these kind of articles having the skin on the steel when they are dipped in the water, it prevents the water from having just the same effect on them as it does on articles previously brightened. I recollect once having a quantity of small drifts to harden, and I was requested to keep the heads soft, so I put a certain number of them in a box, with dust charcoal to heat them, and when sufficiently hot, I shot them in the water with the intention of softening the heads after; but I found upon examining them that I had a number of them very crooked, owing to being very slight, and going from the box so suddenly into the water; so I adopted another plan, by heating a certain number together, and taking them out separately, and dipping them straight and gently into the water, which answered the purpose so far. But it took a little longer to dip them separately; so thinking to save this extra time, I thought I would only dip them in the water as far as I required them hard, and that would save me the trouble of softening the part that was not required hard. But not caring about going ahead with any quantity of things till such time I make myself sure that all is going on well, after I had done about two dozen I examined them, and I did not find one of them but what was cracked at the part that was level with the top of the water, so I dipped the remainder all over, and not a crack appeared in one after. I then made some lead red-hot and dipped the parts that were required soft into it, and accomplished them very nicely. So I think I have said sufficient to convince the reader that what I say is correct, and there are thousands of people that have an opportunity of proving it, and I will speak of nothing but what I have proved from experience to be correct. But to describe minutely the various kinds of articles that I have had to do with would be more likely to tire than to please the reader. But I will give sufficient information, if properly studied, to enable the mechanic to harden and temper any thing that comes to hand. It may be useful to warn the mechanic that drilling too large a centre in articles intended to be hardened is a very great evil, such things as taps, fluted rimers, and such like articles; for when hardened, if the centre is too large, there is almost sure to be a fracture at the bottom of the centre, therefore, it is best, after

the article is finished, to file the centre out, if the centre is not required in; but in some articles the centres are required in them after hardening. But if the hardener should meet with articles that he considers have too large a centre in them, and that there is a risk of having a crack in them, if he stop the centre up with a piece of loom to keep the water out of it, there is little or no danger of its cracking.

I was once working for an employer that had a large order for taps, and he said that he did not approve of cutting the steel down into lengths with a chisel, for he found that a number of his taps had a fracture in them by breaking the steel after it was nicked round with the chisel, which I will admit is often the case if a dull chisel is used to nick it round with, and it will not be visible till after it is hardened, and then it shows. But this was not the case in that instance; for when I examined the taps I found that the centres were to large, and at the bottom of the centres there were the fractures; but I would advise all those that cut their steel down with a chisel, always to keep a good sharp edge on the chisel, for the steel will then break easier, and be less liable to splinter; in hardening a number of articles at one time it is best to put them all into a box together with some dust charcoal, and let them lie till they have acquired the low red heat called cherry red, and then empty the contents of the box into the water, they will then be very clean, without scales, and beautifully hard. It is a very good plan for all small taps; and as it is usual to temper these things to a color after they are hardened, it is necessary to know that they are all hard before beginning to temper them, as it will sometimes happen that there will be some among them that are scarcely hard. If the box has been taken from the fire before it has been properly heated through, then the middle articles in the box will prove not hard enough, so, to make sure of good work, always try them with a smooth file to prove them, for in some instances one bad article would get all the lot condemned, even if all the others were right. But the use of the file can be dispensed with if they are brightened on a buff, or a stone, which are the proper things for the purpose; for the persons that brighten them will find, if they are properly hard, plenty of brisk lively sparks fly from them when they are held on the buff; and if they are not hard enough there will be very little fire in them, therefore, with a very

little attention, those that are soft can be detected and put aside, and heated again with the next batch. Dies may be put in a box, and hardened after the same manner. I have found red-hot lead to be a convenient thing to heat many things in; but to be constantly employed at it, I believe it to be very injurious to health. I have been employed at it for weeks together, and have felt very bad effects from it, and I always avoid using it except in cases of necessity. But there are many things that can be accomplished better by heating them in lead to what they can any other way; such things as long fluted rimers, and various other things that are a great length, for they will always keep straighter by heating them in lead to what they will if they are heated in a common furnace. If the article be very long, it must not be put into the lead too suddenly, or it will be sure to go crooked, for by plunging a cold piece of steel too suddenly into red-hot lead causes it to go crooked, the same if plunged too suddenly into cold water; they should be gradually put into the lead, and gradually into the water, with a little salt in the water to keep it from bubbling, for it is not every thing that can be straightened after it is hard without damaging it, or softening it again. It must always be avoided never to have the lead too hot, or the articles will be spoilt, for they will be found to be full of little holes, if closely examined. Before putting the articles in the lead it is necessary to rub them over with a little soft soap, or mix a little black lead with water and brush them over with it, or plumbers' size, and they will come out of the water clean, without the lead sticking to them. If the black lead is used they must be dried before they are put in the lead, or it is likely to cause the hot lead to fly if they are put in damp; but the soap does not require to be dried.

One advantage in heating large fluted rimers in lead is, if they go crooked in hardening they can be straightened when hard, for as soon as the cutting ribs of the rimer are hot, they must be taken out and put in the water. The middle of the steel will then be quite soft, because, being in the lead such a short time, the middle has not got heated through, consequently the middle cannot harden; if it go crooked, by laying the rimer on a block of hard wood, or a block of lead, and putting a piece of wire into the grove of the rimer, and striking the wire with the hammer, the rimers can then be straightened without breaking them, even when

the cutting edges are dead hard; but if they are tempered before they are straightened, they will straighten the easier. There is little or no danger of breaking them if they are not allowed to get heated all through; such things as these will always be hot on the cutting edges first, which are the only parts required hard. But in respect to small rimers, they cannot be straightened the same way, for they get hot all through almost instantly they are put in the lead, but are not so likely to go crooked as if heated in the fire; small rimers, when they have gone crooked, I have taken them from the water before they have got quite cold, and placed them between two centres, and given them a blow on the full side with a small mallet, or if laid on a block of hard wood it will answer the same. But there is a great risk of breaking them if they are too cold when they are struck with the mallet, therefore, if any prove too crooked to straighten this way it is best to heat them again. But in these kinds of small articles the hardener, if he has a large quantity to do, must always expect a little waste; of small ones I used to average about one in two hundred a waster, and in the large size not one in five hundred. Any quantity of articles, such as drills, bitts, &c., may be expeditiously hardened by dipping their points in the lead, and cooling them in water; a pair of tongs with long jaws is very convenient for holding a quantity at one time; if the articles are of an unequal thickness, and one jaw of the tongs be made hollow and one flat, a piece of soft wood may be put in the hollow jaw, the tongs will then grip them all; any quantity may be hardened as expeditiously as a single article, if there be sufficient lead. Another thing to be observed is, that the surface of melted lead becomes quickly covered with a skin, which is the effect of the air on the surface, and it wastes the lead so fast that it becomes an object of importance to those who use much lead to check its formation, or to convert it when formed into the metallic state again. Charcoal converts the dross into metal again; but if a covering of charcoal or cinders be kept on the lead, the dross will not form, for, allowing it to form the lead is not only wasted, but it is a great obstruction in putting the articles in the lead, likewise in taking them out; any long plate of steel that requires hardening only on one edge, lead is an excellent thing to heat it in, for it need not be heated any farther than where it is wanted hard, and it will then keep straight in harden-

ing. But if it is heated all over in a furnace and put in the water all over, it will be warped all shapes and cause a deal of trouble in setting straight, especially to those who are unacquainted with the setting of hardened steel; and if it is heated all over, and one edge only dipped in the water, the edge that goes in the water will be rounding, and the edge that does not go in the water will be hollow; this is owing to the steel expanding in hardening, for the steel expanding in hardening causes the edge that goes in the water to get longer, and the other edge being kept out of the water, and still hot, the hardened edge expanding longer pushes the other part of the steel round, causing the edge that is out of the water to be hollow. But if it is heated in red-hot lead, and the edge only that is required hard put in the lead, the other part will be quite cold; and when it is put in the water all over the hot part has not sufficient strength in it to alter the cold part, consequently, the cold part of it keeps the hardened part true; the colder the water the more effectually it hardens the steel. Brinish liquids produce rather more hardness than common water, but in most cases common water answers the purpose. But water holding soap in solution prevents the steel from hardening; but as there are many things used in machinery that require to possess the greatest possible degree of hardness, it is necessary with such things to use a saline liquid. Gauges, burnishers, and certain kinds of dies, require to be very hard; also, a file requires a nice, hard tooth. But when steel is required to be made extremely hard it may be quenched in mercury. But this can only be done on a small scale.

## ON THE TEMPERING OF STEEL.

A rod of good steel, in its hardest state, is broken almost as easily as a rod of glass of the same size, and this brittleness can only be diminished by diminishing its hardness; and in this management consists the art of tempering. The colors which appear on hardened steel, previously brightened, are, a light straw color, a dark straw, gold color, brown, purple, violet, and deep blue. These colors appear in succession as the hardness gets reduced. There are various ways of tempering steel, as it depends what the nature of the articles is, likewise the quantity of them,—for, in a number of instances, a great number of articles may be tempered

as expeditiously as a single article. To temper any article to color they must be brightened after they are hardened, and then laid on a plate of hot iron, or upon the surface of melted lead, or in hot sand, or burning charcoal, or held in the centre of an ignited iron ring, or in the mouth of a furnace, or on a gas stove made for the purpose. But in making a furnace for hardening with, it is a good plan to have the top of the furnace made with a good stout plate of cast-iron, so that the plate will always be hot, ready to temper any thing that can be done on a plate. And it will do to put the sand on, and for many other useful purposes, especially if the plate be movable, and a small opening left in the front of the furnace from the top down to the mouth just to admit the tongs. And at any time that hot lead is required, the plate can be removed and the pot of lead placed in the furnace: the plate can then be put back into its place. And the opening in the front will be very convenient for getting the articles in the lead. And when the opening is not required, it may be stopped with a piece of sheet-iron: for by a furnace of this description it is surprising the amount of hardening and tempering that can be accomplished. For large things take a considerable time in heating, and while the hardener is waiting for them getting hot, he may be engaged tempering on the top of the furnace, and still have his attention on the other articles. In the way of case-hardening, a man's sole attention is not required on the articles all the time they are in the fire, as many things lie for hours before they are ready to put in the water, and he may then be engaged in tempering. But if this plate should prove too hot for small articles, another piece of plate may be laid on the top of it, and the articles laid on the top plate. But it is not every one that has large quantities to temper so as to require a furnace or tempering-stove, but having a few articles to do occasionally, such as hobs, taps, dies, drifts, rimers, chases, drills, &c., for the use of the shop. In such cases the use of the furnace can be dispensed with; for a small quantity, they may be heated in a common smith's fire and hardened in the usual way. Taps may then, after they are brightened, be held inside of an ignited iron ring till a dark straw color appears on the surface, and then plunged into cold water. This is the best temper for general use; but if it is intended for any express purpose—for cutting things that are extra hard—in such

cases a light straw color, or yellowish-white, will be required. Hobs require to be a yellowish-white: for as they are always required for cutting steel, it is necessary they should be hard. Fluted rimers may be held inside of an ignited ring and tempered to a light straw color. Dies may be hardened in the usual way, and when brightened placed on a cold plate of iron, and the plate and the dies put upon a large piece of ignited iron and tempered to the same color as a tap,—a straw color. Chases may be hardened in the usual way and placed upon an ignited bar, keeping the threads some distance off the bar, and tempered to a light straw or yellowish-white. Drills may be hardened in the usual way, and the cutting part of the drill tempered to a straw color, while the rest is not higher than blue, so that its liability to break when in use is greatly diminished. Chisels may be hardened in the usual way, and tempered to a violet color; but if intended for cutting stone, a purple is required. Drifts may be hardened in the usual way, and tempered to a brown color. Milling cutters may be hardened in the usual way, and tempered to a yellowish-white. Saws may be hardened in the usual way, in which state they will be brittle and warped. They may then be put into a proper vessel, with as much oil or tallow as will cover them, and placed over a fire and boiled to a spring temper; or they may be smeared with tallow and heated till thick vapors arise and burn off with a blaze. They must then be hammered flat, and afterwards blued. But if they are intended for cutting hard substances, such as steel, or iron, they must be tempered to a straw color.

A very convenient way of tempering, when there is a large quantity of articles to do, is to place them in a vessel with as much tallow or oil as will cover them, and place them over a slow fire till a sufficient heat is given for the temper required. When the oil or tallow is first observed to smoke, it indicates the temper called straw color. And when the smoke becomes more abundant, and of a darker color, this indicates a temper equal to a brown. After which it will yield a black smoke, and still more abundant: this indicates a purple. After which it will take fire if a piece of lighted paper be presented to it, but not so hot as to burn when the light is withdrawn: and this is equal to a blue temper. The next degree of heat will be that which is mostly used for springs, when a white flame will be seen to burn on the articles if they

are lifted out at this heat; after which the oil burns away. To add further oil is useless. Any single article may be smeared with tallow and held over a fire, or in a gas flame, and its temper known in a similar manner. In hardening springs, if they are very slight, oil is the best to harden them in, as they are not so likely to draw out of the proper shape. But if they are stout springs, water is best: for in hardening a stout spring in oil the hardness is confined to the surface. For if the springs are properly hardened, and the steel good, and boiled in oil to the temper I have stated, there is no failing in them. Solid tallow is better than oil for hardening steel which requires considerable hardness, but must not be made brittle. Tallow differs from oil in the absorption of heat for its fusion; for steel that is hardened in oil has always a covering of coal round it which greatly retards the transmission of heat. Water holding soap in solution produces a similar effect. Any large piece of steel may be made sufficiently hard to wear well in machinery, without making it brittle, by hardening it in a body of solid tallow. There is a number of young mechanics that are quite ignorant as to the nature of boiling oil, or tallow, and are anxious to try the experiment of tempering springs in boiling oil. To those we wish to say a few words. I was once asked by a young man the way to harden and temper springs: and I informed him to harden them first, and if he had a quantity to do to temper them in boiling oil,—never thinking that he would attempt to do them on the fire in the house,—and the result was that he nearly set the house on fire. So I have just mentioned this circumstance merely as a warning to the inconsiderate, that they may not fall into the same error, and not to boil oil unless they have a place suitable for it.

## EXPANSION OF STEEL.

It is a well-known fact among those who are in the habit of hardening, that the hardening of steel increases its dimensions. But there may be some that have had very little to do with it that may yet be ignorant of it,—therefore it may be useful to acquaint those with it. But the amount of this expansion cannot be exactly stated, as it varies in different kinds of steel, and even in the same steel operated upon at different heats. But this expansion can be prevented in a great measure by annealing the steel about

three times before the article is completely finished. For instance, when the first skin is taken from the steel, it should be annealed again, and then another cut taken from it and annealed again, and so on for the third time; and I have found that articles treated this way will always keep their size better in hardening than if the steel were only annealed once. But this may appear to some to be a deal of trouble, but they will find there is a saving in the end, as hardened steel is very difficult to work, and the working of hardened steel is very difficult, unknown to a great number of people, and many that know how to work on it have not things convenient for it, such as buffs, laps, or stones. Therefore, to keep the article as near the proper size as possible is a matter of importance. I have had articles that have only been annealed once that have taken many hours to lap to the proper size after hardening; and I have had articles of the same kind, and from the same steel, and hardened at the same heat, that have been annealed three times, that have scarcely required to be touched after they had been hardened.

## ANNEALING OF STEEL.

In annealing of steel, the same care is required in the heating of it as there is in heating of it for hardening, as over-heating the steel is as injurious in one case as in the other. And in the process of annealing, some artists differ very much, some approving of heating the steel and burying it in lime, some of heating it and burying it in cast-iron borings. Others approve of heating it and burying it in saw-dust. But a far better plan is to put the steel into a box made for the purpose and fill it with dust-charcoal, and plug the ends up so that the air is kept from the steel—then to put the box and its contents into the fire till it is heated thoroughly through, and the steel a low red heat. It must be then taken from the fire, and allowed to remain in the box, without opening the box till the steel is cold. And when taken out the steel will be nice and clean, and very soft, and without those bright spots which some mechanics call pins, and which are no small impediments to the filing and working of steel: and, if any difference, the steel is improved by the process. A piece of stout gas-pipe, with a bottom welded in and a plug made for the other end, makes a very good box for a small quantity of steel; but, for a large quantity, the box

must be in proportion to the quantity of steel. If the steel is very large, it is as well to make a charcoal fire to heat it in, and then let the steel and the fire get cold together before it is taken out, and it will be equally soft. But it sometimes happens that a piece of steel is wanted in a hurry, and the steel, perhaps, too hard to work on,—and cannot wait for its being softened in a box. In such cases the steel may be heated in an open fire, and buried in charcoal-dust till it is cold; or, if it be heated to a red heat, sufficient to be seen in a dark place, and then plunged into cold water, it will work more pleasantly,—but not so soft as if it were heated in a box with charcoal. There are many that do not know the value of a good tool, because the steel they work on has never been properly annealed; and before the tool has half done its duty it is worn out, or wants repairing. Whereas, if the steel had been properly annealed, that same tool might have lasted ten times as long without repairing.

## CASE-HARDENING OF IRON.

Case-hardening is an operation much practised, and of considerable use, and in this art there are many different opinions. The prussiate of potash hardens iron nearly as hard as steel by simply heating the iron to a red heat, and putting the potash on it and plunging it in cold water; but this hardness is confined to the surface. But the greatest effect may be produced by an air-tight box and animal carbon alone,—such as horns, hoofs, or leather, just sufficiently burnt to admit of being reduced to powder, in order that more may be got into the box with the articles. Or bones reduced to dust answer the same purpose. The articles intended to be case-hardened are put into the box with animal carbon, and the box made air-tight by luting it with clay. They are then placed in the fire and kept at a light-red heat for any length of time according to the depth required. In half an hour after the box and its contents are thoroughly heated through, it will scarcely be the thickness of a sixpence,—in an hour, double, and so forth, till the desired depth is acquired. The box is then taken from the fire and the contents emptied into pure cold water. They can then be taken out of the water and dried, to keep them from rusting, by riddling them in a sieve with some dry saw-dust, and they are

then ready for polishing. Case-hardening is a superficial conversion of iron into steel. But it is not always merely for economy that iron is case-hardened, but for a multitude of things it is preferable to steel and answers the purpose better. Delicate articles, to keep them from blistering while heating, may be dipped in a solution of salt, and while wet also dipped into a powder of burnt leather, or bones, or other coaly animal matter.

## ON THE SHRINKING OF STEEL.

As a slight mistake at times is the common lot of all, a few words will not be out of place upon the shrinking of such pieces of work that the mechanic may have had the misfortune of boring too large, and which would be useless but for the use of shrinking it smaller. Shrinking is simply heating the steel and plunging it in cold water; but should it not prove small enough the first time, the operation must be repeated—and if insufficient the second time it must be operated upon the third time, which generally effects the purpose. But after the third time I have generally found the hole to cast either oval or bell-mouthed. But after shrinking it the third time, and the article still remaining a waster, there is another source open, which is simply to heat it again and dip it in the water half-way, leaving one-half of it above the water; and then to heat it again, and dip in the reverse way half-way in the water. This will often accomplish what other sources have failed to do. Small holes will shrink rather more if the hole be filled with loam. Shrinking and expansion of steel vary so much, that I have, at a red heat, shrunk the hole in a steel ring considerably; and at a whitish heat, on the same steel, the hole has been considerably larger. Iron rings, or collars, may be shrunk after the same manner as steel, by simply heating and cooling in water.

Much might be said upon the various kinds of tools used in the turnery, but being such a variety of them, differing in form and size, according to the necessities, it would take a whole volume to do them justice. Some turners are apt to think the tools of their own invention best of any, and their attachment to them, not to say bigotry, is often accompanied with a silly attempt to conceal from their fellow-workmen the benefits of their amazing discoveries as to the best shape of a tool. But having had good

experience in tools, and their different shapes, I give it as my opinion that the best shape of a tool is a tool that answers the purpose, does the work well, wherewith least steel is cut to waste in the dressing of it, least time required in the grinding of it, and whose wear is longest without repairing.

## CONCLUSION.

Before I close these details, I wish to offer a few sentiments to the consideration of the young artist interested in them, whether he is one who is anxious to excel in this particular branch of art, as affording the means of honorable livelihood, or claims merely the appellation of an amateur, who studies mechanical operations from the love of knowledge, the desire of amusement, or the hope of celebrity in making discoveries or improvements. Let him not be discouraged by the failure of first attempts. Instead of losing his time in uselessly regretting his disappointment, let him examine into the cause of it, and promptly repeat his experiments with more precaution. It is a mistaken idea that success is absolutely dependent upon length of practice. Uncommon are the cases in which it fails to be the early reward of those who persevere. The reward will always be in proportion to the amount of perseverance and ingenuity displayed. There are always difficulties to contend with for the young beginner. But in every branch of art, if one source of experiment fail, there is abundance of other sources still open. Further practical directions might easily be multiplied, but the necessity for much further minuteness of detail will be removed by a little observation, experience, and perseverance. But those who postpone perseverance, by satisfying themselves with the hope that length of practice will perfect them, will in the end regret their delusion, and may ineffectually try to recover their loss, when habitual languor, and other injurious habits, have rendered the mind averse to observe, and the hand unable to perform.

# APPENDIX.

## THE ANALYSIS OF IRON AND IRON ORES.

### INTRODUCTION.

A FEW general remarks on the examination of minerals may not be unacceptable to some of our readers, wherefore we offer them in the form of an introduction.

We shall take it for granted that our readers are acquainted with elementary chemistry, and also that they have some notion of analytical chemistry; and we shall, on this account, be very brief as regards details, and refer those who may require instruction in manipulation to the excellent works of Dr. Faraday and Greville Williams, Esq.

It may be well here to observe that our object in the following pages is not by any means to attempt to uphold new or unestablished theories, but rather to afford such information as may be *practically* useful; wherefore we shall only make use of such hypotheses as long experience has proved most convenient for the explanation of those varied reactions upon which the phenomena of inorganic chemistry depend.

As the minerals upon which we shall have to operate generally occur in masses, and never in a powder sufficiently fine to require no further pulverization, we may give as the first step in the actual analysis of any ore, that it is to be finely pulverized, in order that it may be readily acted upon by those re-agents with which we purpose to treat it. To effect this pulverization a pestle and mortar will be requisite, consisting of Wedgwood ware, porcelain, steel, or

agate, according to the hardness of the mineral which is being examined.

We may divide the examination of metallic ores under two heads: they consist of complete analysis, or the determination of all or most of the constituents of the ore examined, under the first class; and the second class of analyses consists in the determination of one element only.

The examinations included in the second class are conducted by two methods, the dry way and the wet way; if the former method be adopted, the reactions are produced between the mineral treated and the re-agents used, by the assistance of a high temperature, no solvent being employed in the process except such as act as solvents when fused; this method, however, we do not purpose considering in the present work. In the employment of the second method the elements are caused to act upon each other by being in solution, though in some stages of these operations heat has to be resorted to, without using at the same time any solvent.

We can only conclude that the advantage gained in using solvents at a given temperature, when elements are required to act upon each other, is due to the finely divided state in which the bodies are brought into contact with each other, for we find that some substances, which will not act upon each other when solid, will do so slowly and at ordinary temperatures when finely powdered, and far more rapidly when they are dissolved. Let us now consider the solvents which we may be likely to require in our various operations hereafter to be described.

Water is doubtless the most important of all solvents, for without it we should have but few others; thus sulphuric acid, hydrochloric acid, nitric acid, and ammonia are, for instance, but solutions of those substances of which they bear the names.

There are but few minerals which can be advantageously treated by pure water as a solvent, though they may mostly be decomposed by hydrochloric acid, or by a mixture of hydrochloric and nitric acids, which is called aqua regia. Hence we see that although some substances may not be dissolved in water, they may be dissolved when that solvent also contains some other body, such as hydrochloric acid gas, &c., &c.; though it is true that it very frequently happens that the body to be dissolved first combines with the body already dissolved in the water; or at all events, if the

solution be evaporated to dryness, the two bodies will be found in combination with each other.

The most usual solvent employed in the examination of metallic ores is hydrochloric acid, assisted in many cases by the powerful oxidizing agent, nitric acid; for we may here observe, that until a body is reduced to the condition of an oxide, it cannot be acted upon by acids, as in all cases oxygen is concerned in the reaction.

There are other bodies besides acids which assist in the solution of various substances. Thus, although oxide of copper cannot be dissolved in pure water, it dissolves readily in ammonia, which is an aqueous solution of ammoniacal gas.

Again, alumina will not dissolve in pure water; but it may readily be dissolved in a solution of caustic potassa.

We have now given examples of the solution of substances in acids and alkalies, but salts are also useful in some cases. Thus protoxide of manganese may be retained in solution by chloride of ammonium.

When an oxyacid acts upon a base an action is produced which may be illustrated by the following example: If oxide of iron be operated upon by sulphuric acid, which contains one atom of sulphur and three atoms of oxygen, sulphate of oxide of iron is produced by the combination of the two; but if it be acted upon by hydrochloric acid, which consists of one atom of hydrogen and one of chlorine, chloride of iron is formed by the union of metallic iron with chlorine, whilst the hydrogen of the acid combines with the oxygen of the oxide to form water; thus the effect of a hydracid is very different from that of an oxyacid.

We may therefore say that oxyacids combine with oxides to form one compound; whereas, when an hydracid acts upon an oxide, the radical of the acid combines with the metallic base of the oxide to form a haloid salt.

We will next mention the recovery of a solid body from a solution.

This may be performed in a variety of ways. Thus we may recover substances from a solution by evaporating it to dryness, also by withdrawing or expelling the substance by which it was retained in solution; or finally, by combining the body to be recovered with some element which forms with it an insoluble compound.

If we have oxide of copper dissolved in ammonia. we may re-

cover it by combining the ammonia with an acid, when it will be neutralized, and the oxide of copper will be found at the bottom of the vessel.

Water containing free carbonic acid will dissolve a portion of carbonate of lime; but the free acid can be expelled by boiling, or by filtration through some substance, when the carbonate of lime will be precipitated to the bottom of the solution.

Let us take some examples of the third method of recovering substances from solution.

Acetate of lead is soluble in water containing a slight quantity of free acetic acid; sulphuric acid is soluble in water. If sulphuric acid be allowed to operate upon acetate of lead, the acetic acid is displaced and sulphate of lead is formed; sulphate of lead is, however, insoluble in the water and acetic acid; if, therefore, sulphuric acid is added to a solution of acetate of lead, sulphate of lead will be precipitated to the bottom of the solution, from which the lead itself may be recovered if necessary.

This result will also be obtained, if a soluble sulphate be added to a solution of acetate of lead, and we find, as a general rule, that whenever two elements capable of forming an insoluble compound are brought together in a solution, that compound is formed and is found at the bottom of the vessel.

It has been proposed, as a solution of the question which naturally arises when we see a compound formed by elements arranging themselves in a way which appears contrary to their strongest affinities to form an insoluble compound, that the bodies dissolved are in motion, constantly interchanging their elementary molecules, in proportions dependent upon the relative affinities of the various elements for each other; during which reaction the insoluble compounds would precipitate whenever they were formed, thus putting the elements contained in them out of the reach of further interchange. But we must not occupy our space with speculations of this nature, although their scientific interest is unlimited, and they may result in discoveries practically useful; for it is sufficient for our present purpose to know that whenever the elements of an insoluble compound are in solution together, that compound will be formed and precipitated.

We will now examine the means at hand by which we may separate the various constituents of compounds which we are desirous of analyzing.

Let us suppose, in the first instance, that we have a solid substance, and that we reduce it to a powder, and act upon it with a solvent; say, for instance, that the solid substance contains silica, iron, manganese, alumina, &c., with crystalline carbon. Let us heat this substance in hydrochloric acid, then we may dissolve every thing except the carbon; well, if this is the case, the carbon is evidently separated from the other constituents of the body undergoing examination. But we must clear the solution of the insoluble residue. This is effected by filtering it through unsized paper; the crystallized carbon, known as graphite, will remain upon the filter, where it may be washed by pouring distilled water upon it, in order to free it from all traces of the substances in solution in the liquid.

We may then evaporate the solution to dryness, and again act upon it with the same solvent, when we shall find that there will again be an insoluble residue; but this time it will be silica, which may be collected on a filter as the carbon was before.

We shall now have a number of substances dissolved in the filtrate which cannot be extracted in a similar manner; for if these be recovered by evaporation to dryness, we shall find that dilute hydrochloric acid will dissolve the whole, leaving no residue behind. We must, therefore, look about for some other method of separating the bodies in solution.

If we now cause the iron in solution to take up as much oxygen as it will combine with, and then nearly neutralize the free acid in solution by the addition of carbonate of ammonia, after which we add ammonia and acetate of ammonia, and boil the liquid, the iron will be precipitated, in combination with acetic acid; this may be removed by filtration, and after some time the manganese will also be precipitated.

Thus we succeed in isolating each constituent of the mineral, and this constitutes analysis. Although we purpose to treat of quantitative analysis only in the subsequent sections of this work, we will nevertheless make a few remarks here upon the means of determining the presence or absence of certain substances in a solution. If to a solution of iron we add ferrocyanide of potassium, the precipitate which forms has a blue color; hence, if a solution on the addition of that re-agent exhibits a blue precipitate, iron is present. But the iron may exist as a persalt or as a pro-

tosalt; that is to say, the salt may correspond to sesquioxide or to protoxide of iron.

Let ferrocyanide of potassium in solution be added to the solution of iron, then, if a protosalt be present the blue color will appear, but not otherwise.

If a solution be freed from iron and contain copper, then, on the addition of ferrocyanide of potassium, a brown precipitate will be formed. Also, if the solution be neutralized with ammonia, and an excess of that re-agent be added, a blue solution will be formed.

If bright iron or zinc be placed in an acid solution of copper, the copper will be deposited in the metallic form.

If oxalic acid or oxalate of ammonia be added to a solution of lime, a white precipitate of oxalate of lime will be formed and deposited.

It is needless to multiply examples, but we see that bodies in solution may be recognized by the color of the solution, or by that of the precipitate formed on the addition of certain re-agents.

In a systematic course of qualitative analysis, the experiments must be conducted in such a manner as will allow of the detection of each substance in turn.

The elements also give peculiar tints to flame in which they are volatilized, and each may be identified, even when they are all mixed, if the flame be examined by means of a prism; for, in that case, various colored lines will appear corresponding to the elements present in the flame.

The quantity of some elements in solution may be determined without separating such element from its solution; but before considering this matter we must examine some other points of importance.

It not unfrequently occurs that the state of the substance in solution requires to be altered, oxidized or deoxidized, as the case may be; although it must not be concluded that in every case the amount of oxygen is actually altered, for we use oxidizing agents to convert protochloride of iron into perchloride; but we might in this case call the re-agent a chlorinizing agent, as those we employ sometimes generate chlorine.

Thus, if we oxidize by passing through the solution a current of chlorine, or by the addition of chlorate of potash and hydro-

chloric acid, which will, when heat is applied, liberate chlorine, we may say that the chlorine decomposes the water, releasing oxygen to form peroxide of iron, which is again decomposed by the hydrochloric acid formed by the union of the chlorine with the hydrogen of the water, perchloride of iron being ultimately formed; or we may say that the iron combines with the free, and, in some cases, nascent chlorine, supplied to the solution.

Nitric acid is perhaps most frequently applied as an oxidizing agent, but sulphuric acid, bichromate of potassa, chromic acid, permanganate of potassa, &c., &c., are also applicable.

Sulphurous acid may conveniently be used for the deoxidation of substances in solution, also sulphite of soda. All bodies that absorb oxygen are deoxidizers: as phosphorus, potassium, protosulphate of iron, &c.

We have already stated that some substances may be determined as to quantity without removing them from their solutions; we may take as a fair example of this method, that which is frequently used for the estimation of protoxide of iron.

If permanganate of potassa be added to a solution of protoxide of iron, the former is decomposed and the latter is converted into peroxide; the solution of permanganate of potassa is of a rose tint, which disappears when the salt is decomposed. Let a quantity of permanganate of potassa be dissolved and placed in a burette graduated into one hundred parts; let also a few grains of iron be dissolved in hydrochloric acid, and the permanganate of potassa be added to it, until the tint ceases to be destroyed; then examine the burette to determine the number of divisions which correspond to one grain of iron, when the solution will be ready for use as follows:

Add to the solution containing protoxide of iron the permanganate of potassa, until the rose tint appears; then read off the number of divisions of the burette required, and by the data obtained from the foregoing experiment, calculate the amount of iron present in the solution. This is Margueritte's method.

The quantity of a substance may also be determined by the quantity of a re-agent required to precipitate it.

In some cases it is directed to prepare the normal solution for volumetrical determinations similar to the above by dissolving a given weight of the re-agent used in a certain volume of water,

but we consider it preferable in every case to test the strength of the solution as above.

We must now mention the manipulations requisite when a precipitate is to be weighed.

The precipitate must be collected on a filter and washed until the washings contain no traces of the substances in the filtrate; or in other words the precipitate must be washed until it is perfectly clean.

In some cases the liquid may be decanted off when the precipitate has subsided, which may then be washed by agitation with water, and finally collected on a filter.

If the precipitate will not bear a high temperature, it, together with the filter on which it is collected, must be dried in an air or water-bath at 212° until it ceases to lose weight; the whole is then weighed, and the weight of the filter is deducted from it.

If the precipitate is to be heated to redness, the heat must be continued until the filter is completely consumed, and this may be facilitated by directing a gentle current of oxygen upon it. In this process the precipitate should first be dried, then as much as possible of it should be removed from the filter and placed in the crucible in which the ignition is to be performed; the filter may then be burned and the cinder thus obtained is to be added to the precipitate in the crucible. If the filter leaves an ash, the weight of this, determined by a separate experiment, must be deducted from that of the ignited precipitate.

Some elements are estimated by loss. Thus if we expose peroxide of iron to heat in a current of hydrogen, the oxygen will be withdrawn and the loss of weight of the contents of the vessel in which the operation is performed will be equal to the weight of oxygen originally existing in the peroxide.

This method may also be used for the estimation of iron, which is calculated from the quantity of oxygen combined with it.

## ANALYSIS OF IRON ORES AND IRON.

Before detailing the processes which have been found suitable for the examination of various iron ores and iron, it is desirable to give some account of those minerals from which the iron used in commerce is most generally obtained.

*Magnetic Iron Ore.*—The primitive crystalline form of this substance is the cube; but it also occurs in the form of the octahedron and dodecahedron.

The mineral is somewhat brittle, of an iron-black color, and leaves a black streak.

The ore is magnetic, and has a specific gravity of about 5; it contains about 70 per cent. of metallic iron, consisting of 69 per cent. of peroxide of iron and 31 per cent. of protoxide of iron.

Magnetic iron oxide occurs in granite, gneiss, mica-slate, clay-slate, syenite, hornblende, and chlorite. This ore also occurs in great abundance in the United States, in the Island of Elba, and the iron-sand of New Plymouth, in New Zealand, consists principally of magnetic oxide of iron; some samples of it recently examined containing about 69 per cent. of metallic iron.

It is from this ore also that the celebrated Dánemara iron is prepared.

*Specular Iron—Red Hematite.*—This ore crystallizes in the fourth system, and most generally appears as a modification of the rhombohedron.

The crystals are of a dark steel-gray color; opaque unless in very thin laminæ, in which case they are translucent and of a blood-red tinge; it leaves a reddish-brown streak, and has a specific gravity of from 4·8 to 5·3.

Pure specular iron consists of peroxide of iron, and therefore contains 70 per cent. of metallic iron.

Finely crystallized specimens of this ore are found in the Island of Elba; also at St. Gothard, Arendal, Sweden, Framont, Dauphine, and Switzerland; also in the volcanic districts—as Stromboli and Lipari, Etna and Vesuvius.

Red hematite in reniform masses is found in Cornwall, Ulverstone, Saxony, &c.

*Brown Iron Ore.*—This ore is a mineral which presents in mass a brownish-yellow color; but when pulverized it exhibits a yellow color. Its specific gravity is about 4, and when pure it contains 55 per cent. of metallic iron. It usually occurs in the massive form; but its structure varies according to the locality from which it is obtained.

This ore consists of hydrated peroxide of iron, and is chiefly

confined to the sedimentary formations. This ore is found in Normandy, Berry, Burgundy, Lorraine, &c.

*Iron Pyrites.*—This substance is never treated for the sake of the iron which it contains; but it is frequently employed as a source of sulphur. It crystallizes in the cubic system, is of a bronze-yellow color, with a metallic lustre; it leaves a brownish-black streak. Its specific gravity is from 4·8 to 5·1; it is brittle, and strikes fire with steel.

This ore, when pure, contains two equivalents of sulphur and one of iron.

*Carbonate of Iron* occurs in rhombohedrons and in six-sided prisms, similar to carbonate of lime, from which the crystals differ slightly in the value of their angles.

It is commonly more massive, with a foliated and somewhat curved structure.

This mineral is of a light-gray color; but externally decomposed, it becomes dark-brown, or nearly black. When pure, this mineral consists of carbonate of protoxide of iron. Spathose iron ore is found in rocks of various ages, and is frequently observed to accompany other metallic ores. Carbonate of iron is, however, most plentifully found in gneiss, graywacke, and the coal formation.

The principal deposits in the United Kingdom are at Dudley, Lanarkshire, Ayrshire, and some parts of Wales.

*Chrome Iron Ore.*—This mineral crystallizes in the cubic system. It commonly occurs in the massive form; is of an iron-black or blackish-brown color, and when broken it presents a dull uneven surface. It is slightly magnetic; has a dark-brown streak, and a density varying from 4·3 to 4·5.

Chrome iron consists chiefly of protoxide of iron, alumina, and sesquioxide of chromium. It is ordinarily found in veins traversing serpentine rock. It occurs ordinarily in Styria and in the Shetland Islands.

Amorphous chrome iron is obtained in France, Silesia, Bohemia, and Greenland.

Iron is also a constituent of a very extensive variety of minerals: but we only deem it necessary to mention such as are useful in metallurgy, or are likely to come into the metallurgist's hands. We have therefore, with the exception of one or two ores, passed in silence such as are not used in the manufacture of iron.

We will now pass on to describe various methods of estimating iron, of separating it from other bodies, and of performing analyses of various descriptions of iron ores.

Ores, the constituents of which are known, may in many cases require the iron only to be determined. But when such components as sulphur and phosphorus occur, it is highly desirable to determine the proportion in which they exist, as this knowledge will enable us to form an opinion as to the quality of the iron obtained from such ore. In many cases it will be desirable to perform a complete analysis of the ores. Cast-iron and steel are analyzed to ascertain the quantity of carbon and other foreign elements contained in them, and it is also desirable to examine such specimens of wrought or malleable iron as may exhibit peculiar properties or great strength, as thereby some valuable information may be obtained.

*Estimation of Iron.*—In estimating iron, it is usual to weigh it in the state of peroxide, which contains 70 per cent. of metallic iron. When this oxide exists ready-formed in a liquid, it may most conveniently be precipitated either by ammonia or by carbonate of ammonia; but the oxide must be precipitated from a heated solution, otherwise it will be deposited as a gelatinous mass which cannot be easily purified by washing. If iron exists in a solution, the state of protoxide, it is necessary, previous to precipitation, to convert it into peroxide,—which may be effected by boiling with nitric acid or chlorate of potassa, or by passing a current of chlorine gas through it. In the latter case, however, it will be necessary to remove the excess of chlorine by subsequent ebullition of the solution. The iron being peroxidized, may then be precipitated by ammonia.

Chlorate of potassa should only be used when the solution contains hydrochloric acid. The oxidizing effect is due to the liberation of chlorine.

There is some danger of error occurring from the use of ammonia to precipitate the iron, as a slight excess of that re-agent will re-dissolve a portion of the precipitate, thereby vitiating the results.

It is desirable, on this account, where greater accuracy is required, to precipitate the iron in the form of succinate or benzoate and in some cases as basic acetate. The salt thus obtained is de-

composed by heating in a platinum crucible, and then weighed as peroxide. It occasionally happens that the operator is obliged to throw down the iron by means of an excess of caustic potassa; but when this course is pursued the precipitate contains traces of potassa, which can only be removed by long-continued washing. Should the amount of sesquioxide of iron be large, it may most readily be freed from potassa by re-dissolving the precipitate in hydrochloric acid, diluted, and re-precipitating it by succinate or benzoate of ammonia, after carefully neutralizing the solution.

When the solution also contains organic matter, such as sugar, starch, or some of the vegetable acids, the iron cannot be precipitated either by ammonia or its carbonate, and it must be treated with sulphide of ammonium, which precipitates the whole of the iron as sulphide. To obtain the iron in the state of sesquioxide, this precipitate should be thrown on a filter and carefully washed with a very dilute solution of sulphide of ammonium. This last is added in order to prevent the formation of sulphate of iron, which would be dissolved and carried through the filter, thereby occasioning loss.

When the precipitate has been sufficiently washed, it is digested in hydrochloric acid; the solution is then peroxidized and precipitated by succinate, benzoate, or acetate of ammonia.

*Estimation of Iron in Iron Ores.*—We will, under this heading, insert various methods of estimating iron which have been proposed as suitable for the determination of iron existing in ores of that metal.

*Fuch's Method.*—The specimen is to be dissolved in strong and pure hydrochloric acid, and peroxidized, either by adding, cautiously, crystals of chlorate of potassa, or by passing a current of chlorine gas through the solution.

The peroxidation is ascertained by testing with ferricyanide of potassium, which produces a blue precipitate with protoxide of iron, but none with peroxide.

The solution having been peroxidized, it is to be boiled for a few minutes in order to expel any excess of chlorine which may exist.

A weighed quantity of pure copper is then introduced, and the boiling is then continued until the color of the solution changes to a pale yellow-green. When no further change of color is ob-

served to take place, the flask must be filled up with hot water, and the copper removed, washed in cold water, dried, and weighed.

The loss of weight indicates the amount of chlorine consumed to convert the original protochloride into perchloride of iron; every equivalent of copper and every equivalent of chlorine converting two equivalents of protochloride of iron into perchloride.

It follows that every equivalent of copper corresponds to two equivalents of perchloride of iron in solution; or, what amounts to the same thing, to two equivalents of peroxide of iron in the substance analyzed,—which peroxide of iron contains 70 per cent. of metallic iron.

Taking the equivalent of copper at 31·66, and that of iron at 28, it follows that for every 100 parts lost from the weight of the copper there exists in the solution 176·88 parts of metallic iron.

This method requires very great care in order to give results at all approaching the truth, and it is totally inapplicable when the solution contains arsenic.

*Margueritte's Method.*—This method is based upon the employment of a standard test solution, and on the reciprocal action of the salts of protoxide of iron and permanganate of potassa, whereby a quantity of the latter, exactly proportional to the quantity of protoxide of iron present, is decomposed.

The ore is dissolved in hydrochloric acid, and the metal is brought to the minimum of oxidation, which is done by treating the solution with sulphate of soda, and boiling to expel the excess of sulphuric acid. The solution of permanganate of potassa is now cautiously added, until the pink color of the test solution appears. And the number of divisions of the burette required to effect this is accurately noted.

The permanganate is decomposed so long as any protosalt of iron exists in the solution; but when it has all been converted into a persalt, the permanganate then added remains undecomposed, and is detected by its color. The solution must contain no substance that may decompose the permanganate, therefore all the excess of sulphurous acid must be carefully expelled.

Copper and arsenic interfere in this manner with the accuracy of the process, and, according to Dr. Noad, were the only metals found to do so. But a slight modification of the process overcomes

these difficulties, which are created by the reduction of the compounds of those metals by the sulphite of soda.

The operation is proceeded with as usual, except that after having expelled the excess of sulphurous acid by ebullition, a piece of pure laminated zinc is added, which, acting upon the hydrochloric acid, disengages hydrogen; arsenic and copper are reduced to the metallic state. When the solution of the zinc is complete, the precipitated particles of arsenic and copper are removed by filtration, and the clear liquor proceeded with as before.

To prepare the permanganate of potassa, 7 parts of chlorate of potassa, 10 parts of hydrate of potassa, and 8 parts of peroxide of manganese, are intimately mixed; the manganese should be reduced to the finest possible powder, and the potassa, having been dissolved in water, is mixed with the other substances, dried, and the whole heated to dull redness for an hour. The fused mass is then digested in as little water as will dissolve the salt; and to this solution is added nitric acid, until it assumes a rich violet tint. It is subsequently filtered through asbestos (an organic filter would decompose the permanganate of potassa) in order to separate the peroxide of manganese suspended in the solution. The solution must be carefully protected from contact with organic matter, even the small particles in the atmosphere affecting it.

To convert the liquor into a standard test solution, a given quantity, say 10 grains, of pure iron, is dissolved in hydrochloric acid. When the solution is complete, the liquid is diluted with about half a pint of cold water, and the solution of the permanganate of potassa is added until the pink color reappears, and the number of divisions of the burette requisite to produce this is carefully noted,—from which the value of the solution may be readily calculated.

*Dr. Penny's Method.*—This method is based upon a reciprocal action existing between chromic acid and protoxide of iron, whereby a transference of oxygen takes place, the protoxide of iron becoming converted into sesquioxide, and the chromic acid into sesquioxide of chromium.

The iron in clay-band and black-band iron stone being chiefly in the condition of carbonate of iron, is boiled in hydrochloric acid, in order to convert the metallic salt into a protochloride, and the standard solution of bichromate of potassa is then added, until

the solution is peroxidized, which is ascertained by frequently testing it with ferricyanide of potassium. When the blue precipitate is no longer formed the protosalt is entirely converted into a persalt.

The test solution is thus prepared: 44·4 grs. of the salt in fine powder are weighed out and put into a burette, graduated into 100 parts, and the instrument is filled to 0 with warm distilled water.

The burette is then closed by the palm of the hand, and its contents are agitated until the salt is completely dissolved and the solution rendered of uniform density throughout. Each division of the solution thus prepared contains 0·444 grs. of the bichromate of potassa, which Dr. Penny found to correspond to half a grain of metallic iron.

The bichromate must be pure, and should be thoroughly dried by heating to incipient fusion.

*Estimation by means of hydrogen.*—This method may be employed when all the iron exists as sesquioxide, and no other substance capable of being reduced by hydrogen is present.

The mineral, in a fine powder, is carefully ignited in the air, and then in hydrogen. The hydrogen, which should be quite dry, abstracts the oxygen from the sesquioxide, and the amount of iron contained in the compound may be calculated from the loss of weight.

Sesquioxide of iron contains 30 per cent. of oxygen. Therefore, for every 100 parts of weight lost by ignition in hydrogen, the substance examined contains 233·33 parts of metallic iron.

We will now explain various methods of separating iron from other substances.

*Separation of Protoxide of Iron from Peroxide of Iron.—Fresenius's Method.*—On the property possessed by salts of the protoxide of iron to resist decomposition by boiling with an earthy carbonate, is based a process for its separation from peroxide of iron, when the two exist in solution together.

When boiled with carbonate of baryta, the salt of the peroxide only is decomposed; the solution, filtered from the precipitated peroxide and excess of carbonate of baryta, is boiled with nitric acid to convert the protoxide of iron into peroxide, which last is precipitated by ammonia after the baryta has been separated by the addition of sulphuric acid.

*Rose's Method.*—Dissolve a weighed quantity of the mixture in hydrochloric acid; peroxidize the protoxide by boiling with nitric acid.

Then precipitate the iron by ammonia, dry, and weigh. The increase of weight upon that of the original mixture is caused by the acquisition of oxygen, which converts the protoxide into peroxide. During the process of peroxidation every two equivalents of protoxide combines with one equivalent of oxygen; hence every 100 parts of increased weight represent 700 parts of metallic iron in the form of protoxide, or 900 parts of the protoxide.

As the quantity of oxygen taken up in this process is exceedingly small, the experiments must be very carefully performed, the error occurring in the increase of weight being multiplied nine times in the final result.

*Rose's Method, 2d.*—The mixed oxides are converted into metallic iron, by ignition in a current of dry hydrogen, and the water formed, as also the quantity of iron reduced, is ascertained.

*Wood's Analysis.*—The quantity of peroxide of iron in a solution of protoxide and peroxide in hydrochloric acid may be determined in the following manner.

The compound is powdered finely and placed in a flask, from which the whole of the atmospheric air is expelled by a current of carbonic acid gas; sufficient hydrochloric acid to dissolve the powder is added, and the flask is quickly and securely closed. The solution of the powder being completed, recently-prepared and perfectly clear sulphuretted hydrogen water is added in excess, the flask again closed, and the whole allowed to remain at rest for some days. The peroxide of iron is reduced to protoxide by the sulphuretted hydrogen, and a proportional quantity of sulphur is deposited. This is carefully collected on a small weighed filter, and washed and dried at a gentle heat. The filter must be protected from the atmosphere during the process of filtration.

From the quantity of sulphur deposited, the amount of peroxide of iron originally present may be calculated.

Every 16 parts of sulphur indicate 70 parts of peroxide of iron.

*Fuch's Method.*—This method of determining the peroxide of iron is detailed at page 380.

The quantity of protoxide of iron present in the solution of the two oxides may also be determined by the volumetrical method of Margueritte or Penny.

In conducting these various processes intended for the determination of the proportions in which the peroxide and protoxide of iron exist when they are together in a compound, great care must be taken during the solution of the substance to be analyzed that no possibility occurs either of the peroxidation of the protoxide, or of the reduction of the peroxide.

*Separation of Peroxide of Iron from Protoxide of Manganese.*—This may be effected by precipitating the iron from a neutral solution by succinate or benzoate of ammonia, which re agents do not precipitate protoxide of manganese. If any iron exists in the solution as protoxide, it must first be converted into peroxide by boiling with nitric acid, or with hydrochloric acid and chlorate of potassa.

If the solution is acid it must be neutralized by ammonia, chloride of ammonium being added to prevent the precipitation of protoxide of manganese. A slight excess of ammonia may be added, so that a trace of peroxide of iron remains undissolved when the solution is heated.

Succinate of soda, or succinate or benzoate of ammonia, may be used as the precipitant. The precipitate, which is bulky, should be washed with caustic ammonia while on the filter, in order to remove the greater portion of the organic acid, that there may be less risk of reducing a portion of peroxide during the ignition of the precipitate. From the filtrate, protoxide of manganese may be precipitated by soda. Peroxide of iron and protoxide of manganese may also be separated in the following manner: Dissolve the oxides in hydrochloric acid, and boil the solution with carbonate of baryta or with carbonate of lime; the perchloride of iron is decomposed with precipitation of the peroxide; and the formation of a corresponding quantity of chloride of barium or chloride of calcium; while on the contrary, the protochloride of manganese is not affected by the earthy carbonate. The latter is added to the solution of the two oxides, so long as effervescence, due to the escape of carbonic acid, continues. When effervescence has ceased, the solution is boiled for a short time and then filtered. The precipitate of peroxide of iron, with excess of earthy carbonate, is then dissolved in hydrochloric acid; and if carbonate of lime has been used, ammonia is added, to re-precipitate peroxide of iron, avoiding exposure to the air as much as possible, to prevent the

absorption of carbonic acid and formation of carbonate of lime. If carbonate of baryta has been used instead of carbonate of lime, baryta may first be separated from the solution in hydrochloric acid by sulphuric acid, after which the solution is filtered and the peroxide of iron precipitated by the addition of ammonia.

The solution, filtered from the precipitate of peroxide of iron and excess of earthy carbonate, contains chloride of manganese, and also chloride of calcium or barium. If the former, oxide of manganese is separated as follows: Chloride of ammonium is first added to the solution (unless it contains a large quantity of free acid) to prevent precipitation by ammonia, which is next added; after which the manganese is precipitated as sulphide by sulphide of ammonium. The precipitate is collected, washed with a very dilute solution of sulphide of ammonium, and dissolved in hydrochloric acid; the solution is then heated until the sulphuretted hydrogen thus formed is completely expelled, which is known by the solution becoming inodorous. The solution is now filtered and the manganese precipitated by carbonate of potassa. The solution filtered from the sulphuret of manganese containing lime (and the same process is effectual, if it contains magnesia) is acidified by hydrochloric acid, boiled to expel sulphuretted hydrogen, and filtered. The filtered solution is then supersaturated with ammonia, and the lime is precipitated as oxalate by oxalate of ammonia or oxalic acid. The separation is also effected in the following manner: Carbonates of manganese and lime are precipitated by a fixed alkaline carbonate, the solution being boiled at the time of precipitation. The precipitate is ignited at a dull red-heat, to convert the carbonate of manganese into manganoso-manganic oxide ($Mn_3O_4$), and is then treated with very dilute nitric acid: this solution dissolves the lime with effervescence, leaving the oxide of manganese unacted upon, which may be collected upon a filter, washed, ignited, and weighed.

Any trace of manganese dissolved by the nitric acid may be precipitated by sulphide of ammonium, after neutralizing the acid by caustic ammonia.

This process is also suitable for the separation of manganese from magnesia, which behaves in every respect as the lime.

If carbonate of baryta has been used to decompose the chloride of iron, the baryta may be separated by sulphate of soda, which

will precipitate sulphate of baryta; the solution may then be filtered, and the oxide of manganese precipitated as carbonate of potassa.

A similar process is frequently used to effect the separation of peroxide of iron from other oxides whose solutions in hydrochloric acid are not decomposed when boiled with carbonate of lime or baryta. Two precautions must be adopted in this process—1. That neither sulphuric, phosphoric, arsenic, nor boracic acid is present in the solution; and 2. That all the iron exists in the state of peroxide, as salts of the protoxide of iron are not decomposable by carbonate of lime.

*Separation of Iron from Cobalt and Nickel.*—The solution of iron is then peroxidized, and the iron is then precipitated by succinate or benzoate of ammonia, and the cobalt and nickel in the filtrate are separated by one of the following methods.

*Phillip's Method.*—Both the oxides are to be, if not already in solution, dissolved in an acid, and the solution supersaturated with ammonia, having previously added a sufficient quantity of chloride of ammonium to prevent precipitation; the solution, which is of a sky-blue color, is then largely diluted with water which has been previously well boiled to expel atmospheric air: caustic potassa is added to the solution, and the vessel is closed with a cork; oxide of nickel is thus precipitated, but the oxide of cobalt remains in solution; when the former has completely settled, the supernatant liquid, which should have a rose-red tint, is filtered off, and the oxide of nickel washed with hot water, ignited, and weighed; the oxide of cobalt in filtrate is precipitated by sulphide of ammonium.

The reason which renders it necessary to use water free from atmospheric air for the dilution of the solution is, that air would cause the formation of peroxide of cobalt, which, precipitating as a black powder, would contaminate the oxide of nickel. The more dilute the solution is, the less easily does the oxide of cobalt become peroxidized.

When much ammoniacal salt is present, a very considerable quantity of caustic potassa is required to precipitate the oxide of nickel.

According to Fresenius, the separation by this method is not perfect, the cobalt invariably retaining a trace of nickel, and the precipitated nickel often containing traces of cobalt.

*Liebig's Method.*—Hydrochloric acid is added to the solution of the two metals, and then cyanide of potassium, in such excess that the precipitate at first formed is re-dissolved, the whole is boiled, adding from time to time hydrochloric acid, until hydrocyanic acid ceases to be evolved. An excess of caustic potassa is then added, and the boiling is continued until the hydrated protoxide of nickel is completely precipitated; the solution is then filtered, and the filtrate contains the whole of the cobalt in the form of cobalticyanide of potassium; it is evaporated to dryness with excess of nitric acid, the residue fused, and treated with hot water; peroxide of cobalt remains, which is dissolved in hydrochloric acid, precipitated as oxide, by potassa, and reduced by a current of hydrogen and heat, and then weighed.

*Rose's Method.*—This process is founded upon the greater tendency of protoxide of cobalt than of protoxide of nickel to peroxidize.

Both metals are dissolved in hydrochloric acid; the solution must contain a sufficient excess of free acid; it is then diluted with a considerable quantity of water.

As cobalt possesses a much higher coloring power than nickel, the diluted solution is of a rose color, even when a great quantity of nickel is present; a current of chlorine is then passed through the solution for several hours.

Carbonate of baryta in excess is added, and the whole allowed to stand for eighteen hours, being frequently agitated; the precipitated peroxide of cobalt and the excess of carbonate of baryta are well washed with cold water, and dissolved in hot hydrochloric acid; after the separation of the baryta by sulphuric acid, the cobalt is precipitated by hydrate of potassa, and after being washed and dried, is placed in a platinum capsule and reduced by hydrogen gas.

The filtrate from the oxide of cobalt is of a pure green color, and does not contain a trace of that element. After the removal of baryta by means of sulphuric acid, the oxide of nickel is pre cipitated by caustic potassa.

*Frederick Field's Method.*—The method of separating iron from either cobalt or nickel, or both, consists in precipitating the iron by means of oxide of lead (litharge): the process is conducted in the following manner.

The mixed metals are brought into solution as nitrates, and the solution is then evaporated nearly to dryness, water is then added, and also oxide of lead, after which the solution is briskly boiled for ten minutes or a quarter of an hour, the iron is entirely precipitated from the solution, the other nitrates remaining dissolved. After filtration sulphuric acid is added, and the liquid is allowed to stand for sixteen hours to precipitate the lead, after which the nickel and cobalt may be determined as in the last method, but it is preferred to precipitate the nickel, as peroxide of hypochlorite of soda.

The peroxide of nickel, after boiling the solution in which it is suspended, separates as a dense precipitate, and can be readily washed, but the precipitation should be performed in an open vessel, in order to facilitate the removal of flakes from the sides, which are somewhat liable to be formed there. The peroxide is heated to whiteness, and the nickel is then weighed as protoxide. This method appears from the experiments of its inventor to be exceedingly accurate and expeditious.

*Separation of Iron from Alumina.*—The solution containing the peroxide of iron and the alumina is concentrated by evaporation, and digested with excess of caustic potassa, in which the alumina alone is dissolved.

*Knop's Method.*—The above process is used, but with the addition of sulphide of ammonium, to effect complete precipitation of the iron, or, when practicable, the two oxides are precipitated by sulphide of ammonium, the precipitate being washed with a very weak solution of sulphide of ammonium, and the alumina is subsequently extracted by potassa, to which a few drops of sulphide of ammonium have been added.

*Berthier's Method.*—The moist hydrates are boiled with sulphurous acid, when the alumina is deposited, the iron remaining in solution.

To prevent an ochrous deposit from the action of the air, the solution should be boiled in a long-necked flask, and when sulphurous acid ceases to be evolved, it should be filled with boiling water, and corked; when it has become cold, the liquid is decanted on to a filter, replaced by boiling water, and finally filtered and edulcorated. Phosphoric acid is carried down by the alumina, but arsenic acid is not.

In the above process, the solution of sulphurous acid may be replaced by sulphite of ammonia, the iron is thereby reduced to protoxide, and the alumina is precipitated.

*Separation of Iron from Magnesia.*—Chloride of ammonium is added to the solution, in order to prevent the precipitation of the magnesia, but this is not necessary, if the solution of the oxides contains a considerable excess of hydrochloric acid. Caustic ammonia is then added to precipitate the iron as peroxide, which, however, carries down some of the magnesia with it, from which it is freed by again dissolving in hydrochloric acid and precipitating the iron by succinate, benzoate, or acetate of iron. The two solutions of magnesia are mixed, and the magnesia is completely precipitated by phosphate of soda. The whole is then well agitated, and allowed to stand for several hours.

The precipitate is collected on a filter, washed with water containing about one-eighth of ammonia. The washed salt is dried and carefully ignited, together with the filter. The ignited salt is then weighed: it is the pyrophosphate of magnesia, and contains 36·46 per cent. of magnesia.

*Separation of Peroxide of Iron from Baryta.*—To the solution of the two oxides sulphate of soda is added, whereby the baryta is precipitated as sulphate, and from the filtered solution peroxide of iron is precipitated as above directed.

*Separation of Peroxide of Iron from Yttria,—Berthier's Method.*—The moist hydrates of the oxides are boiled with sulphurous acid, whereby the yttria will be deposited, the iron remaining in solution. To prevent the formation of an ochreous deposit from the action of the atmospheric air, the solution should be boiled in a flask with a long neck, and when no more sulphurous acid is disengaged, it should be filled with boiling water and corked; when it has become cold, the liquid is decanted on to a filter, replaced by boiling water, and finally filtered and edulcorated.

*Scherer's Method.*—To a neutral solution of the oxides, oxalate of potassa is added, whereby the double oxalate of yttria and potassa will be formed, which will gradually appear as a crystalline precipitate, which, by ignition, is converted into yttria and carbonate of potassa; this mixture is dissolved in hydrochloric acid, diluted with much water, and the yttria is then precipitated by caustic ammonia; it must then be well washed with boiling water, after which it may be ignited and weighed.

*Separation of Iron from the Alkalies and Alkaline Earths.*—This may be effected either by ammonia or its succinate, but when alkaline earths are in solution with iron, care must be taken that the ammonia used be perfectly caustic, for should any carbonic acid be present, the precipitate would become contaminated with the carbonates of the alkaline earths present in the solution. If the iron is to be separated from magnesia, a sufficient quantity of chloride of ammonium must be added to retain that earth in solution, otherwise it will be precipitated by the ammonia. This precaution will, however, be rendered unnecessary, if the solution contains much free hydrochloric acid, as in that case chloride of ammonium will be formed on the addition of ammonia.

*Separation of Iron from Silica.*—This is readily effected when the bodies are in solution, by evaporating to dryness, and redissolving in dilute hydrochloric acid, when the silica will remain insoluble, and may be separated by filtration, dried, and weighed.

It frequently happens that the silicate cannot, even by protracted boiling, be decomposed by hydrochloric or nitrohydrochloric acid, and in this case it must be decomposed by one of the following methods before it can be brought into solution.

*Fusion with an Alkaline Carbonate.*—The silicate in the finest possible state of division is mixed in a platinum crucible with three or four times its weight of anhydrous carbonate of soda, or with an equal quantity of well-dried carbonate of potassa, or with a mixture of both. The crucible is then placed in a furnace, and at first heated gently; but subsequently to intense ignition, at which it must be maintained for from thirty minutes to one hour. When the crucible is cool, the contents are dissolved out carefully; the crucible being placed in a beaker and drenched with water, after which hydrochloric acid is added by degrees, by which carbonic acid will be evolved; the beaker is then covered and heated gently until the whole is dissolved, except, perhaps, a few flakes of silica. If heavy, gritty particles subside, the decomposition has been imperfect, and the experiment must be re-commenced on another portion of the mineral.

*Fusion with Caustic Potassa.*—The finely-pulverized mineral is mixed in a silver crucible with four or five times its weight of caustic potassa; the cover is placed on the crucible, and it is then carefully heated to dryness over a lamp, and the dry mass is sub-

sequently heated to redness, after which the contents of the crucible may be dissolved in hydrochloric acid.

*Abich's Method.*—The mineral is fused with four or six times its weight of carbonate of baryta. The most intense heat is required —no action taking place until fusion has been induced, after which rapid decomposition proceeds, the operation being concluded in a quarter of an hour. No silicate has been found to withstand the action of this agent.

Hydrate of baryta may also be used, and in this case the operation may be conducted in a silver crucible over a good spirit-lamp. Four or five parts of the hydrate deprived of its water of crystallization are mixed with one of the mineral and covered with a layer of carbonate of baryta. The decomposition being complete, the analysis is proceeded with in the usual manner.

*Berzelius's Method.*—This method consists in attacking the mineral with hydrofluoric acid. The finely-powdered mineral is placed in a shallow platinum dish, standing in the centre of a leaden dish about six inches in diameter. The bottom of the dish is covered with a layer about one-quarter of an inch thick of a paste made of powdered fluor-spar and sulphuric acid. The mineral is slightly moistened, and the cover having been put on the dish, it is gently warmed, hydrofluoric acid is liberated, which will, in about one hour and a half, decompose about twenty-five grains of silicate. During the process the powder must be moistened once or twice. The decomposition being complete, the powder is moistened with concentrated hydrochloric acid until hydrofluosilicic ceases to be evolved, when the excess of sulphuric acid is expelled by evaporation to dryness, after which the powder may be dissolved in dilute hydrochloric acid, and examined in the usual way.

*Separation of Iron from Chromium,—Rose's Method.*—To a solution of the metals add tartaric acid, to prevent precipitation by potassa, which is then added, and the iron is precipitated by sulphide of potassium. The filtered solution is evaporated to dryness, ignited, fused with carbonate of soda and nitrate of potassa. The alkaline chromate thus formed is dissolved, and the chromium precipitated by baryta or lead, and weighed as chromate of baryta or lead. The precipitants are used in the form of nitrates.

*Liebig's Method.*—The solution is saturated with sulphuretted hydrogen to reduce the iron to protoxide (a few drops of sulphide

of ammonium answers the purpose), and it is then thrown down by cyanide of potassium, and an excess of the latter added; the iron then dissolves as ferrocyanide of potassium, but the oxide of chromium remains insoluble, and may be dried and weighed.

*Separation of Iron from Lime, Strontia, and the Alkalies.*—This may be readily effected by caustic ammonia, which precipitates peroxide of iron only. In the cases of strontia and lime, access of air must be avoided, as otherwise a portion of the lime or strontia might be precipitated as carbonate, and for the same reason, the ammonia must be perfectly pure and caustic.

*Separation of Iron from Lantanum and Cerium.*—The lantanum or cerium may be precipitated as oxalate by oxalate of potash, double oxalates being gradually formed while the iron remains in solution. By heating to redness the mixture is converted into carbonate of potassa and oxide of cerium or lantanum, as the case may be. The mixture is dissolved in hydrochloric acid, and the solution diluted, after which the oxide of cerium or lantanum is precipitated by caustic ammonia.

*Separation of Iron from Carbonic Acid.*—The carbonic acid may be evolved by means of a mineral acid and estimated as loss. The operation may be conveniently conducted in the apparatus of Parnell, or of Fresenius and Will: in both, means are provided to arrest the aqueous vapor, which might otherwise be carried off without the carbonic acid. Parnell's consists of a flask, in which is the carbonate and a tube of acid—a tube passes through the cork of the flask and is connected at its outer extremity with a tube filtered with chloride of calcium, to arrest aqueous vapor. The apparatus, when supplied with the carbonate and fitted together, is inclined, when the acid runs from the contained tube, and decomposes the mineral; the last portions of carbonic acid are expelled by heat. In Fresenius and Will's apparatus, two flasks are used, and the aqueous vapor is absorbed by sulphuric acid. Whichever method we adopt, the flasks must be weighed before and after the operation, the difference being the quantity of carbonic acid.

The carbonic acid in carbonate of iron may also be expelled by heat and estimated as loss.

*Separation of Iron from Phosphoric Acid.*—Phosphoric acid when free, may be estimated as pyrophosphate of magnesia; chloride of

ammonium, ammonia, and sulphate of magnesia are added to the solution, which is then well agitated. The mixture is allowed to rest for several hours; it is then filtered, the precipitate washed with water containing a little ammonia, in which it is almost insoluble; the precipitate is then ignited—first gently, then strongly, to convert it into pyrophosphate of magnesia, which contains 63·54 per cent. of phosphoric acid.

*Fresenius's Method.*—The solution is boiled, removed from the lamp, and sulphite of soda added, until the color has become pale-green and carbonate of soda produces a white precipitate: it is then boiled until the smell of sulphurous acid disappears, any excess of free acid is neutralized with carbonate of soda, a few drops of chlorine water added, and excess of acetate of soda. The phosphoric acid is precipitated as perphosphate of iron. Chlorine water is now added until the liquor appears reddish. It is boiled until it becomes clear, filtered hot, and the precipitate washed with hot water. The precipitate contains the phosphoric acid as perphosphate of iron, with a little basic peracetate of iron. The precipitate is dissolved in hydrochloric acid, reduced with sulphite of soda, and boiled with potassa or soda till it is black and granular. It is dissolved in hydrochloric acid and added to the other solution of iron, from which the other elements have previously been separated. The filtered solution contains the phosphoric acid, which is precipitated and treated as above.

*Separation of Sulphur from Iron.*—Dissolve the mineral slowly in hydrochloric acid, pass the evolved gas through acetate of lead, in a solution acidified with acetic acid; sulphide of lead is precipitated: this is converted into sulphate of lead by digestion in fuming nitric acid; from the weight of the sulphur, the amount of sulphur is calculated.

*Bromeis's Method.*—The powder is acted on by sulphuric acid diluted, and the evolved gas is passed through an ammoniacal solution of silver, and the sulphur is then weighed as sulphide of silver.

We have now, as far as is consistent with the object of the present work, detailed the various methods of separating iron from those elements with which it is commonly associated in nature, and we will therefore pass on to an account of a variety of methods employed for the complete analysis of samples of iron ores, such as are used in commerce, and of commercial iron.

*Analysis of Cast-Iron.*—The following method of analyzing cast-iron and iron ores is extracted from the published report of the experiments on cast-iron conducted at Woolwich, and ordered by the House of Commons to be printed, 30th July, 1858. The process was adopted in the examination of numerous specimens, the analyses being performed by Mr. John Spiller and Mr. Arthur Reynolds.

*Preparation of the Sample.*—Preparatory to its examination, the metal was reduced to a suitable state of division, by boring, turning, or planing. In the case of white iron, it was broken to a coarse powder in a steel crushing-mortar. It was considered preferable to prepare an average sample of the pig by boring across it, so that a fair proportion of the graphite, which was occasionally concentrated towards the centre of the pig, might be included in the sample. The five borings obtained in this way were further reduced when necessary, and thoroughly mixed by trituration in a Wedgwood mortar.

*Chemical Analysis.*—In the analysis of pig-iron, the proportions of the following constituents were usually determined: Manganese, carbon, silicon, sulphur, phosphorus; and in certain cases, metals, such as arsenic, lead, and copper, when their existence in appreciable quantity had been discovered in the ores from which the iron had been obtained.

For this purpose, four portions were usually weighed out:

*a.* 100 grains for sulphur, carbon existing as graphite, silicon, and manganese;

*b.* 50 grains for phosphorus;

*c.* 50 to 100 grains for determining the existence and amount of combined carbon;

*d.* 500 grains for metals existing in the iron in minute proportions.

*Sulphur.*—One hundred grains of the iron borings were slowly dissolved in concentrated hydrochloric acid, the evolved gas being passed through a solution of acetate of lead, slightly acidified with acetic acid, the sulphuretted hydrogen disengaged together with hydrogen, precipitated the sulphide of lead, which was collected on a filter, washed, burnt, and subsequently (in the customary manner) converted into the sulphate of lead, from the weight of which the per-centage of sulphur was calculated.

The contents of the flask, after the metal had been fully acted upon, were transferred to a porcelain basin and evaporated to dryness, the mass digested with concentrated hydrochloric acid, and water afterwards added. The insoluble residue, consisting of silicic acid and graphite, was collected on a filter, the filtrate being reserved for the estimation of manganese.

*Carbon as Graphite.*—The mixed silicic acid and graphite were separated by the action of a warm solution of pure potassa, when the silicic acid was dissolved, the graphite, which remained insoluble, was again collected, washed with dilute hydrochloric acid and water, and dried; it was afterwards carefully removed from the paper by scraping with a knife-blade, and transferred to a platinum crucible, in which, after exposure for some time to about 300° F., it was weighed. Upon subsequently burning the graphite in a muffle, it usually left a very small quantity of reddish ash, which was deducted from the former weight.

*Silicon.*—The amount of silicic acid dissolved by the potassa was recovered in the usual manner by evaporation with hydrochloric acid; the residue was digested with water, collected, washed, dried, and weighed. The amount of silicon in the iron was calculated from the silicic acid obtained.

*Manganese.*—The hydrochloric acid solution, separated from the silicic acid and graphite, was divided into two equal portions, one of which, representing fifty grains of iron, was always sufficient for the estimation of the manganese. The iron in the liquid having been peroxidized by boiling the hydrochloric acid solution, and adding occasionally a little chlorate of potassa, the acid was to a great extent neutralized by the addition of carbonate of ammonia. Sufficient acetate of ammonia was afterwards added for the conversion of the chloride of iron into acetate, and the liquid was boiled, when the iron was completely separated as insoluble basic acetate.

The filtrate containing manganese was rendered alkaline with ammonia, and after the addition of a few drops of bromine, set aside for about eighteen hours. The hydrated binoxide of manganese, which had separated from the liquid, was afterwards collected, washed, dried, and ignited at a high temperature, when it was weighed as manganoso-manganic oxide ($Mn_3O_4$), which furnished by calculation the quantity of manganese.

*Phosphorus.*—For the estimation of phosphorus, fifty grains of the iron borings were acted upon with warm nitro-hydrochloric acid, in a flask with a long neck, and after complete solution of the metal, the contents of the flask were transferred to a porcelain basin, and evaporated to dryness. The residue was moistened with concentrated hydrochloric acid and again evaporated, so as thoroughly to expel nitric acid. The residue then obtained was dissolved in hydrochloric acid, the solution diluted, filtered, nearly neutralized with carbonate of ammonia, and the iron in solution reduced to protoxide, by the addition of sulphite of ammonia to the gently-heated liquid, and the subsequent careful addition of dilute sulphuric acid to expel excess of sulphurous acid. Acetate of ammonia and a few drops of solution of sesquichloride of iron were then added, and the liquid boiled, when the phosphoric acid was precipitated as basic phosphate of sesquioxide of iron, with some basic acetate. The liquid was rapidly filtered, with as little exposure to the air as possible, the precipitate was slightly washed and dissolved in hydrochloric acid, the solution neutralized with carbonate of ammonia, and sulphide of ammonium added. It was then gently heated, to insure the conversion of phosphate into sulphide of iron. The latter was afterwards removed by filtration, washed with dilute sulphide of ammonium, and the phosphoric acid was precipitated from the solution in the usual manner as ammonio-phosphate of magnesia, and weighed as pyrophosphate of magnesia, from which the phosphorus was calculated.

*Combined Carbon.*—After numerous comparative trials of the several methods in common use for determining the total amount of carbon in cast-iron, that which was ultimately adopted (after necessary experiments had fully established its accuracy) consisted in dissolving the metal in an acid solution of chloride of copper, collecting and washing the insoluble residue which remained after the complete action of this solvent, and submitting it, when dry, to combustion with oxide of copper in a current of oxygen, the source of heat employed being the gas combustion-furnace. The total amount of carbon in the iron was then calculated from the weight of carbonic acid absorbed by solution of potassa in the usual manner. The carbon existing in a state of combination with the iron was represented by the excess which this process afforded over that of the direct estimation of carbon as graphite, in the manner already described.

*Minute Proportions of Foreign Metals.*—About 400 or 500 grains of the iron were employed in the examination for metals precipitated by sulphuretted hydrogen, *e.g.*, lead, copper, arsenic, &c. The iron was dissolved in hydrochloric acid, and the solution, diluted and partly neutralized with carbonate of soda, was submitted to the action of sulphuretted hydrogen. After saturation with the gas, the liquid was allowed to stand at rest for several hours, and the small quantity of sediment which had subsided was examined for metals by the ordinary analytical processes.

*Analysis of Iron Ores.*—The analytical processes employed for the separation of the various constituents occurring in iron ores, were in a great measure identical with those employed in the examination of metallic iron: thus the estimation of oxide of manganese was conducted in a precisely similar manner, and with the exception that no process of reduction was required in the case of clay ironstone, and other ores containing the iron already in the state of protoxide, the phosphoric acid was determined by the same process as that employed for the estimation of phosphorus in pig-iron. The amount of metallic iron and its condition of oxidation in the ore were determined by Margueritte's volumetrical method with standard solution of permanganate of potash, while the proportions of lime, magnesia, carbonic acid, water (hygroscopic and combined), insoluble residue, and the nature of this latter, were determined by following the analytical processes invariably employed in mineral analyses of this description.

*Analysis of Clay Ironstone,—Purnell's Method.*—The ordinary constituents of this ore are, carbonic acid, silica, protoxide and peroxide of iron, alumina, magnesia, lime, and protoxide of manganese. Its complete analysis may be effected in the following manner: The powdered mineral is boiled in aqua regia, with effervescence of carbonic acid and separation of silica, with perhaps a little alumina as insoluble residue. These are estimated by ordinary processes. The solution, which contains all the bases, with perhaps the exception of a little alumina, is evaporated to dryness: the residue is re-dissolved in dilute hydrochloric acid, and the solution is filtered. Unless the solution is very acid, chloride of ammonium is now added, and afterwards excess of caustic ammonia, which precipitates peroxide of iron and alumina with small quantities of protoxide of manganese and magnesia. From

the solution filtered from this precipitate lime is to be precipitated as oxalate, by oxalate of ammonia or oxalic acid. The precipitate by ammonia being filtered and washed, is dissolved in a small quantity of hydrochloric acid. This solution is then boiled with excess of caustic potassa, to dissolve the alumina at first precipitated by potash, which may be estimated by the usual method. The portion insoluble in excess of potassa is re-dissolved in pure hydrochloric acid, the solution is carefully neutralized with ammonia, and the peroxide of iron precipitated as succinate or benzoate, with the precautions already described. The filtered liquid, containing small quantities of magnesia and protoxide of manganese, is mixed with that filtered from the oxalate of lime; and from the mixture manganese is precipitated as sulphuret by sulphide of ammonium from the filtered solution, and after the separation of this precipitate, the magnesia is separated as ammonio-phosphate by phosphate of soda with ammonia.

If the amount of iron only is required, add ammonia in excess to the solution in aqua regia; after washing, boil the precipitate in solution of caustic potassa, to dissolve alumina, re-dissolve the peroxide of iron in hydrochloric acid, and again precipitate it by ammonia; dry, ignite, and weigh.

*Analysis of Spathose Iron Ore; Woehler's Method.*—Dissolve the powdered mineral in hydrochloric acid, adding nitric acid; during the process, dilute the solution, and neutralize it with carbonate of soda until it becomes of a brownish color, when a concentrated solution of acetate of soda is to be added, and the whole heated to the boiling-point. In this manner, iron, and iron only, is precipitated, the precipitate being a salt of the peroxide. The filtrate is to be neutralized, mixed with hypochlorite of soda, and allowed to stand for twenty-four hours, when the manganese will be precipitated as the oxide, having the symbol $MnO_2$. The application of heat transforms it into manganoso-manganic oxide ($Mn_3O_4$). The liquid filtered from the manganese precipitate should be examined for lime and magnesia.

*Second Method.*—Dissolve as before, and precipitate all the iron by carbonate of soda, stirring the solution during the process; the other bases remain dissolved in the free carbonic acid. The solution should be much diluted.

*Another Method, Conington.*—Dissolve the finely-pulverized ore

in hot hydrochloric acid, peroxidize the solution by means of nitric acid or chlorate of potassa, then add caustic ammonia until a precipitate begins to appear, after which precipitate the iron by sulphide of ammonium, filter off the solution, rapidly wash the precipitate with water, containing a few drops of sulphide of ammonium, ignite, and weight it.

Acidify the filtrate with hydrochloric acid, evaporate the solution to dryness, and heat the residue, to volatilize the ammoniacal salts; dissolve again in hydrochloric acid, saturate the solution with chlorine, and precipitate the manganese by caustic ammonia, filter, rapidly ignite, and weigh as usual. The other ingredients are determined as usual.

*Analysis of Chrome-Iron Ore.—(Noad's Manipulation and Analysis.)*—The mineral is first reduced to a fine powder, after which it is to be fused with caustic potassa (an alkaline carbonate is not applicable). The fused mass is digested in water, which dissolves the chromate of potassa, together with the excess of potassa. The oxide of iron remains behind, together with, perhaps, a small quantity of undecomposed ore, which is separated from the sesquioxide of iron by hydrochloric acid; from the solution in hydrochloric acid the iron is precipitated by ammonia, and the chromic acid in the aqueous solution is reduced to sesquioxide of chromium by hydrochloric acid and alcohol.

If the mineral contained alumina, it will be found in the aqueous solution with the alkaline chromate, and will be precipitated with the oxide of chromium, from which it is separated in the following manner.

The mixture of the two oxides is fused with twice its weight of carbonate of soda, and twice and a half its weight of nitrate of potassa. The oxide of chromium becomes converted into alkaline chromate, which is extracted with water, and the alumina which remains undissolved is freed fiom alkali by solution in hydrochloric acid and precipitation by ammonia.

According to Dr. Schaffhaur, a portion of the alumina in this process always dissolves along with the alkaline chromate. He therefore recommends to convey the precipitate obtained by adding ammonia to a solution of the two oxides into a hot concentrated solution of caustic potassa, and to boil the whole down until near solidification; when quite cold, water is added, and the whole

of the alumina dissolves without carrying with it a trace of oxide of chromium.

*Woehler's Method.*—The finely-powdered ore is intimately mixed with four parts of bisulphate of potassa, and raise the whole to a red heat. A sufficient time for the complete decomposition of the mineral having elapsed, the mixture is allowed to cool, after which a double quantity of equal parts of carbonate of soda and nitrate of potassa are added, and the mixture is again fused, in order to obtain an alkaline chromate. The mass having been allowed to cool, the alkaline chromate is extracted by water, and the insoluble residue is treated as usual.

*Analysis of Red Hematite.*—This ore usually contains sesquioxide of iron, some alkaline carbonates, and admixture of the matrix in which the ore is found.

*Fresenius's Method.*—The mineral is first pounded, and dried at 212° F. Treat the dried mineral with dilute nitric acid, or with boiling acetic acid, in order to dissolve out the alkaline carbonates, which may be estimated in the usual manner, from this solution. Filter off the solution, and dry and ignite the residue as usual, and then place it in a porcelain boat, which is put into a porcelain tube and heated to redness, whilst a current of dry hydrogen is passed slowly over it. The loss of weight in this last operation expresses the amount of oxygen in the sesquioxide of iron, from which the iron may also be calculated. The residue is then treated with hydrochloric acid, by which the iron is dissolved, and it is then immediately determined volumetrically by the method of Margueritte or by that of Penny. Wash the insoluble residue dry, ignite, and weigh.

The water and carbonic acid may be determined by a separate ignition, being estimated as loss. (In order to determine the quantity of each of these ingredients, the water may be arrested by a tube containing chloride of calcium).

*Analysis of Brown Hematite.*—This ore usually contains hydrated sesquioxide of iron, alumina, sesquioxide of manganese, lime, magnesia, silica, phosphoric acid, sulphuric acid, and admixture of matrix.

*Fresenius's Method.*—(Recommended for ores containing only a small quantity of silica, alumina, lime, and magnesia.) Fuse the dry pulverized mineral with thrice its weight of carbonates of soda

and potassa. When cold, digest the fused mass in water, filter, and wash the residue. Acidify the filtrate with hydrochloric acid, and separate the silica; add a few drops of solution of chloride of barium, and let the liquor stand for twenty-four hours; after which filter from sulphate of baryta. Remove the excess of baryta by means of sulphuric acid, and precipitate the phosphorus as pyrophosphate of magnesia in the following manner. To the solution containing the phosphoric acid add a clear mixture of sulphate of magnesia, caustic ammonia, and chloride of ammonium, until its odor is evolved, and let the mixture stand for twelve hours in the cold; filter and wash the precipitate with water containing one-third of solution of ammonia, until the rinsings after the addition of hydrochloric acid cease to be rendered turbid by chloride of barium; dry the precipitate, place it in a platinum crucible and heat, first gently, then to intense redness, and weigh it as pyrophosphate of magnesia.

Digest the residue in hydrochloric acid, in a flask placed obliquely, until the decomposition is complete; dilute and filter from the residual matrix, which wash, dry, ignite, and weigh.

Determine the sulphuric acid in the filtrate by chlorate of barium. Evaporate the solution to expel excess of acid, dilute, add carbonate of soda, and precipitate with carbonate of baryta; let the liquor stand for half an hour, and then filter. Dissolve the precipitate in hydrochloric acid, precipitate the baryta by sulphuric acid; filter and add ammonia, until the solution is alkaline; filter from the precipitate, which wash, dry, and ignite. It contains sesquioxide of iron, alumina, phosphoric acid, and silica. Digest in hydrochloric acid, and separate the silica, reduce the filtrate by sulphate of soda, and determine the iron, alumina, and phosphoric acid.

Acidify the alkaline filtrate, and boil with chlorate of potassa, separate alumina and phosphoric acid.

In the filtrate determine alumina and the alkaline earths. In this method the presence of copper and arsenic is neglected.

*Another Method.*—Digest the mineral in hydrochloric acid, and treat the insoluble residue by the first method. Evaporate the solution in hydrochloric acid to dryness, and separate the silica; reduce the filtrate by sulphite of soda, and expel the excess of sulphurous acid by heat; saturate the solution with hydrosulphuric

acid; if a precipitate is produced, test it for copper and arsenic. Expel the hydrosulphuric acid by heat, precipitate with carbonate of soda, and add caustic potassa in excess; boil and filter. A black precipitate and an alkaline filtrate are obtained. The former contains oxides of iron, and perhaps carbonate of manganese and carbonates and phosphates of lime and magnesia. Dissolve in hydrochloric acid and separate phosphoric acid with sesquioxide of iron; filter, then separate, and return the sesquioxide of iron to the other solution.

Acidify the solution of alkaline phosphate by hydrochloric acid, and set aside to add to the solution of phosphoric acid.

Treat the filtrate from the phosphoric acid and iron, to separate iron, manganese, lime, and magnesia. Acidify the alkaline filtrate, which contains alumina and phosphoric acid; boil with chlorate of potassa, precipitate by ammonia, and add chloride of barium; digest and filter; the precipitate contains all the alumina and phosphoric acid; the latter is combined with the alumina and baryta.

Wash and dissolve in as little hydrochloric acid as possible, heat, saturate with carbonate of baryta, add soda, and precipitate the baryta by carbonate of soda, and filter. The alumina is in the solution, and the phosphoric acid is in the filtrate.

Acidify the solution with hydrochloric acid, and boil with chlorate of potassa; precipitate by the addition of chloride of ammonium and caustic ammonia; boil, filter, and wash the precipitate; dissolve in hydrochloric acid, precipitate baryta by sulphuric acid, and determine phosphoric acid in filtrate by precipitation by magnesia.

Determine the sulphuric acid as directed in the first method.

*Analysis of Titanic Iron Ore.—Woehler.*—Fuse the finely-powdered ore with bisulphate of potassa at a red heat; when the fused mass is cool, dissolve in water; saturate with ammonia, and precipitate by sulphide of ammonium the iron and titanic acid.

Wash the precipitate with sulphuric acid, to dissolve out the iron—the titanic acid remains behind as an insoluble white powder.

*Another Method.*—Raise the powdered mineral to an intense heat in a slow current of hydrogen, to reduce the iron, which may be subsequently extracted by hydrochloric acid.

*Analysis of Bog-Iron Ore,—Woehler's Method.*—The mineral is

dissolved in hydrochloric acid, evaporated to dryness at 212° F. re-dissolved in warm dilute hydrochloric acid, and filtered to remove the sand and liberated silicic acid.

The solution should then be boiled with sulphate of soda, to reduce the peroxide of iron to the protoxide, and the arsenic acid to the metal (until no odor is perceptible); the arsenic is then precipitated by sulphuretted hydrogen as sesquisulphuret, which may contain copper.

After removing this precipitate by filtration, the solution should be boiled to remove sulphuretted hydrogen, when carbonate of soda may be added, and the whole boiled with excess of caustic soda, until the precipitate is converted to a powder.

The solution, after filtering, contains alumina and part of the phosphoric acid; and the precipitate consists of protoxide and peroxide of iron, carbonates of manganese and carbonates and phosphates of lime and magnesia. It should be dissolved in hot nitric acid, the solution partly neutralized with carbonate of soda and boiled with acetate of soda. By this process all the oxide of iron and phosphoric acid are precipitated, which may be separated as usual. The filtered solution contains the protoxide of manganese, lime, and magnesia, which may also be separated in the ordinary way.

*Analysis of Furnace Slag,—Woehler.*—The powdered mineral is digested in hydrochloric acid mixed with nitric acid until it becomes a yellow gelatinous mass, when it is evaporated to dryness on a sand-bath. The residue is digested in weak hydrochloric acid, and the silica reduced by filtration is washed, dried, and weighed.

The iron is precipitated from the solution by ammonia. If lime and magnesia are present, they are obtained from the filtrate from the iron precipitate. The lime is precipitated by oxalate of ammonia, and is ignited and weighed as carbonate; and the magnesia is precipitated by phosphate of soda, ignited and weighed as pyrophosphate.

*Analysis of Meteoric Iron,—Muller's Method.*—The powdered mineral is dissolved in dilute hydrochloric acid in a tubulated retort. The hydrogen disengaged is passed through bulbs containing nitrate of copper, in order to arrest any hydrosulphuric acid which may be evolved. The sulphur obtained is oxidized by boiling in nitric acid, and weighed as sulphate of baryta.

The solution is filtered from the insoluble residue and saturated with hydrosulphuric acid; sulphur and a trace of copper are deposited. The solution is oxidized, and the iron precipitated as sulphide, which is, however, partly soluble in presence of phosphoric acid.

The phosphoric acid is estimated by fusing the mineral with carbonate of soda, and precipitating it by magnesia.

Nickel, cobalt, and manganese are precipitated by sulphide of ammonium, the iron in this case being separated by carbonate of baryta. The nickel and cobalt may be separated by Liebig's method, or by precipitating the cobalt, by means of carbonate of baryta, from a solution which has been previously treated with chlorine or bromine. The residue is levigated, by which is obtained a black flocculent matter and a black shining substance. The former dissolves in hydrochloric acid, evolving hydrosulphuric acid. The black shining mass dissolves completely in warm nitro-hydrochloric acid; the solution is mixed with soda and carbonate of potassa, and evaporated to dryness, and fused, to remove phosphoric acid. Iron and nickel are determined as above. This is the method which was used by Muller in the analysis of some specimens of meteoric iron from Zacatecas, in Mexico.

# GLOSSARY.

*Air-condenser.*—Is a condenser where air is the cooling medium, steam being contained within the vessel, which may be of tubes or flat plates, around which a current of air circulates.

*Air-jackets.*—Are air spaces left around steam-cylinders and boilers to prevent the dispersion of heat.

*Air-pumps.*—Are pumps used to remove the air, vapor, and water from the condensers of steam-engines.

*Air-vessels.*—Are fixed upon the discharge-pipes of force-pumps to equalize the pressure of water, and to prevent the occurrence of shocks.

*Argillaceous.*—Clayey.

*Ball-valve.*—A valve formed by a sphere fitting a spherical seat.

*Balance levers.*—Are weighted levers used to open the valves of Cornish and other pumping-engines.

*Belly.*—The central part of a blast-furnace.

*Bevel-wheels.*—Tooth-wheels, having their teeth at an angle to the axis.

*Bell-crank.*—A lever, having its arms at right angles.

*Bilge-pumps.*—Are used for removing the bilge-water in ships.

*Blast-furnace.*—An upright furnace used for smelting iron.

*Blooms.*—Masses of wrought-iron, as furnished from the puddling-forges.

*Blow-holes.*—Air spaces which sometimes occur in castings.

*Blowthrough Cocks.*—Are applied to steam-engines to allow steam to be blown through cylinder and condenser before starting.

*Body.*—The upper part of the blast-furnace.

*Boring-bars.*—Carry the tools by which cylinders are bored.

*Boring-heads.*—Short cylinders, which carry cutting-tools, and are placed upon boring-bars.

*Boshes.*—Lower part of the blast-furnace.

*Boss.*—Circular elevations to receive the pressure of nuts, bolt-heads, &c.; also central projections, to which the arms of the wheels, &c., are attached.

*Botryoidal.*—A term applied to minerals, of which the fracture is conchoidal.

*Brine-pumps.*—Are used to discharge salt-water from marine boilers, at intervals, to prevent super-saturation and deposition of salt.

*Broaches.*—Tools for smoothing cylindrical or conical holes.

*Buckets.*—Pistons fitted with valves to allow of the passage of fluid through them in one direction.

*Bucket-pumps.*—Pumps furnished with buckets.

*Buddles.*—Apparatus for washing minerals.

*Cams.*—Discs upon which bosses or protusions are formed, either upon the periphery or the face.

*Carbonates.*—Compounds of earth or oxides with carbonic acid.

*Carrier.*—A piece of apparatus used to secure the revolution of work in a lathe.

*Cataract.*—A species of brake, which is used to govern the velocity of Cornish pumping-engines.

*Centre-punch.*—A pointed punch used to mark out work.

*Chucks.*—Apparatus connected with turning lathes, to which the work to be operated upon is secured.

*Clack-valve.*—A valve opening on a hinge placed at one edge.

*Clinkers.*—Slags or scoriæ which form in furnaces

*Clothing.*—Covering applied to steam-boilers, cylinders, &c., to prevent loss of heat.

*Collar-bolt.*—A bolt forged with a shoulder or collar.

*Cotter-joint, Gib, and.*—A joint made with a key and wedge.

*Counter.*—An instrument for recording the number of strokes or revolutions made by machinery.

*Cores.*—Pieces of baked earth, used to produce cavities in castings.

*Core-prints.*—Projections on patterns left to form recesses in moulds, in which to rest cores.

*Cross-heads.*—Cross-beams carried at the upper ends of piston and other rods.

*Cross-tails.*—Similar to cross-heads, but fixed at the lower extremities of rods.

*Cupola.*—A small blast furnace, used to melt iron for castings.

*Cyanogen.*—A gas consisting of carbon and hydrogen.

*Cylinder ports.*—The steam-passages through which steam is admitted to the working cylinder of an engine.

*Deoxidation.*—Removal of oxygen from bodies with which it is combined.

*Detent,*—A catch to arrest the teeth of wheels or racks.

*Dividing-engine.*—A machine to effect the graduation of scales.

*Disengaging-gear.*—Gear for stopping and starting engines.

*Donkey-engines.*—Small engines used to feed steam-boilers.

*Double-beat valves.*—Valves formed with two seatings.

*Drifts.*—Tools used to clear square and polygonal holes.

*Dynamics.*—The science which treats of the motion of bodies.

*Eccentric.*—A wheel fixed eccentrically upon a shaft to produce rectilineal from rotative motion.

*Eccentric strap.*—A band surrounding the eccentric, and within which the eccentric revolves.

*Equilibrium-valve.*—A valve so formed that it is unaffected by fluid pressure in either direction.

*Exhaust port.*—The opening by which waste steam leaves the working cylinder.

*Expansion-valve.*—A valve used to cut off the supply of steam at any position of the engine.

*False seams.*—Ridges produced on castings where the mould is joined.

*Feed-pump.*—A pump used to supply steam-boilers.

*Ferruginous.*—Containing iron.

*Flasks.*—Boxes in which moulds for castings are made.

*Fluxes.*—Materials used to dissolve scoriæ and protect surfaces from oxidation.

*Fly-wheel.*—A heavy wheel employed to equalize the motion of machinery.

*Floats.*—A kind of file, but having redges instead of teeth.

*Gab-lever.*—An eccentric rod having a gap to embrace the valve-gear

*Galena.*—A combination of sulphur and lead.

*Gates or Gits.*—Air and feed-holes left in moulds for castings.

*Gauge-cocks.*—Cocks fixed at various levels in a steam-boiler to show the height of the water level.

*Gauge-glass.*—A glass tube connected at top and bottom with the boiler to show the water level at sight.

*Gib and Cotter-joint.*—*See* Cotter.

*Gits.*—*See* Gates.

*Gland.*—The cover of a stuffing-box.

*Governor.*—An instrument to regulate the motion of a prime mover.

*Grease-cock.*—A cock to allow of the entrance of grease to steam-cylinders, &c., without loss of steam.

*Gudgeons.*—Short shafts, pins, or studs acting as axes of retation or oscillation.

*Heads.*—The standards which carry the centres of a lathe.

*Heads-boring.*—*See* Boring-heads.

*Heads-cross.*—*See* Cross-heads.

*Hearts.*—The vessels making the communications between the various tubes of Craddock's boiler.

*Heat, latent.*—Heat which has disappeared during liquefaction or gasification.

*Heats, specific.*—The relative quantities of heat contained by various bodies of equal weight.

*Hob.*—A kind of screw used to make dies and screw-cutting tools

*Hub.*—*See* Boss.

*Homogenity.*—Uniformity of texture and constitution.

*Horn-plates* —The plates which guide and retain the axle-boxes of railway and other vehicles.

*Horse-power.*—One horse-power is equal to 33,000 foot-pounds of work per minute.

*Hot well.*—A cistern into which the water, &c., from the condenser of a steam-engine is raised by the air-pump.

*Indicator.*—An instrument for determining the pressure in the cylinder of a steam-engine.

*Injector, Gifford's.*—An instrument for feeding boilers by means of a jet of steam.

*Injection-cock.*—The cock which regulates the admission of water to the condenser.

*Jigging.*—Washing minerals in a sieve.

*Journal.*—That part of a shaft which is in contact with the bearings.

*Joule's equivalent.*—The amount of work found by Dr. Joule to be equivalent to one unit of heat, the work being expended in the production of friction, 772 foot-pounds.

*Junk rings.*—The rings by which piston packings are retained in position and tightened-up when necessary.

*Leading screw.*—That screw by which the slide-rest of a screw-cutting lathe is caused to progress along the lathe bed.

*Latent heat.*—*See* Heat, latent.

*Mandril.*—The shafts in the head-stock of a lathe which carries the centre.

*Manhole.*—An opening in a steam-boiler to admit a man to clean it.

*Matrix.*—The soil surrounding a mineral which adheres to it when it is excavated.

*Mitre wheels.*—Bevel wheels, having their teeth at an angle of 45° to the axis.

*Moment of force.*—The intensity of a rotating force, multiplied by its distance from the centre of rotation.

*Mud-hole.*—An aperture in the lower part of the boiler to allow the sediment to be washed out.

*Nozzles.*—The extremities of the steam and exhaust passages of the cylinder of a steam-engine.

*Oxidation.*—The combination of oxygen with any substance.

*Oxides.*—Compounds of oxygen with various bodies.

*Packing.*—Metal, india-rubber, or hemp, employed to prevent the escape of steam past the moving parts of an engine.

*Pall.*—*See* Detent.

*Plug-rod.*—Rod by which the valve-gear of a pumping-engine is wrought.

*Plummer-blocks.*—Carry the bearings of shafts.

*Poppet-head.*—The back head of a lathe.

*Ports.*—*See* Cylinder ports.

*Power*—Work divided by time.

*Prints.*—*See* Core prints.

*Pump buckets.*—*See* Buckets.

*Reniform.*—Of a kidney shape.

*Rhymers.*—*See* Broaches.

*Riggers.*—Pulleys by which motion is transmitted through bands.

*Ring-valves.*—Double-beat valves, having the two beats in the same plane.

*Roasting.*—An operation to remove sulphur, arsenic, and other volatile ingredients from minerals to be smelted.

*Scabs.*—Defects on castings produced by the peeling of the mould.

*Shank.*—A large ladle used by moulders.

*Silicates.*—Combinations of silicic acid with various bases.

*Slag or Scoriæ.*—The refuse from smelting operations.

*Snap.*—A swage used for forging the heads of rivets.

*Snugs.*—Projections to afford means of attachment or to fix the position of plummer blocks, &c.

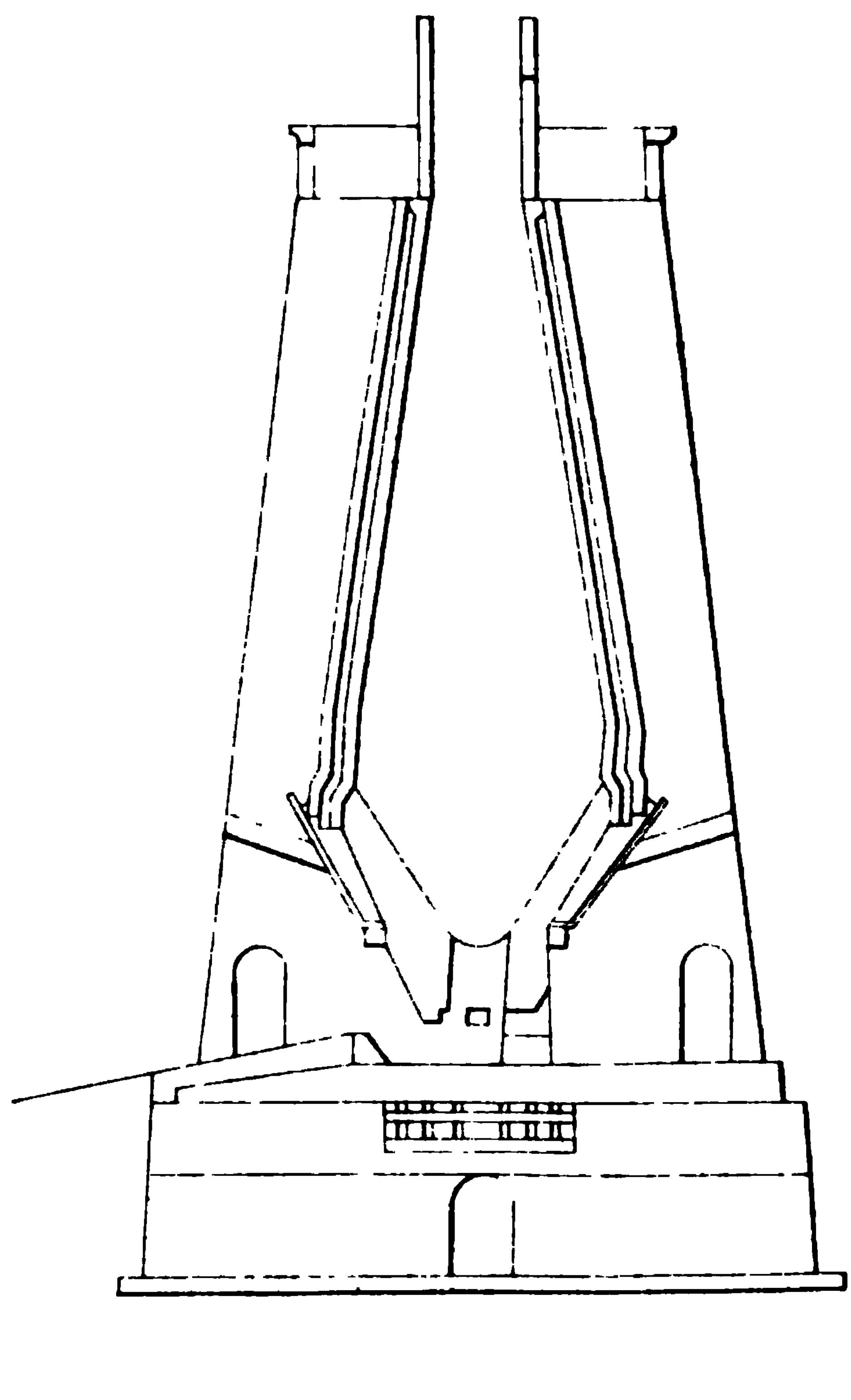
*Spur wheels.*—Tooth wheels.

*Spring beams.*—Stout beams that receive the blow at the termination of the stroke of a Cornish engine.

*Steam-jacket.*—Steam space left around a working cylinder.
*Steam-ports.*—*See* Cylinder ports.
*Sulphates.*—Compounds of sulphuric acid with various bases.
*Sulphides or Sulphurets.*—Compounds of sulphur with various elements.
*Superheaters.*—Apparatus for elevating the temperature of steam above that due to its pressure.
*Tang.*—That part of a file or chisel that is inserted in the handle.
*Taps and Dies.*—Tools for making nuts and screws.
*Template.*—A gauge showing the profile of any required work.
*Trunnions.*—The journals by which oscillating cylinders are supported.
*Tue-iron.*—The nozzle through which the blast is supplied to a forge.
*Tunnel-hole.*—The opening through which a blast furnace is fed.
*Tuyer.*—*See* Tue-iron.
*Valves.*—Apparatus to regulate the flow of liquids and gases.
*Weld.*—A joint made by hammering or pressing metals together when hot.
*Work.*—A pressure multiplied into the space through which it acts.

# INDEX.

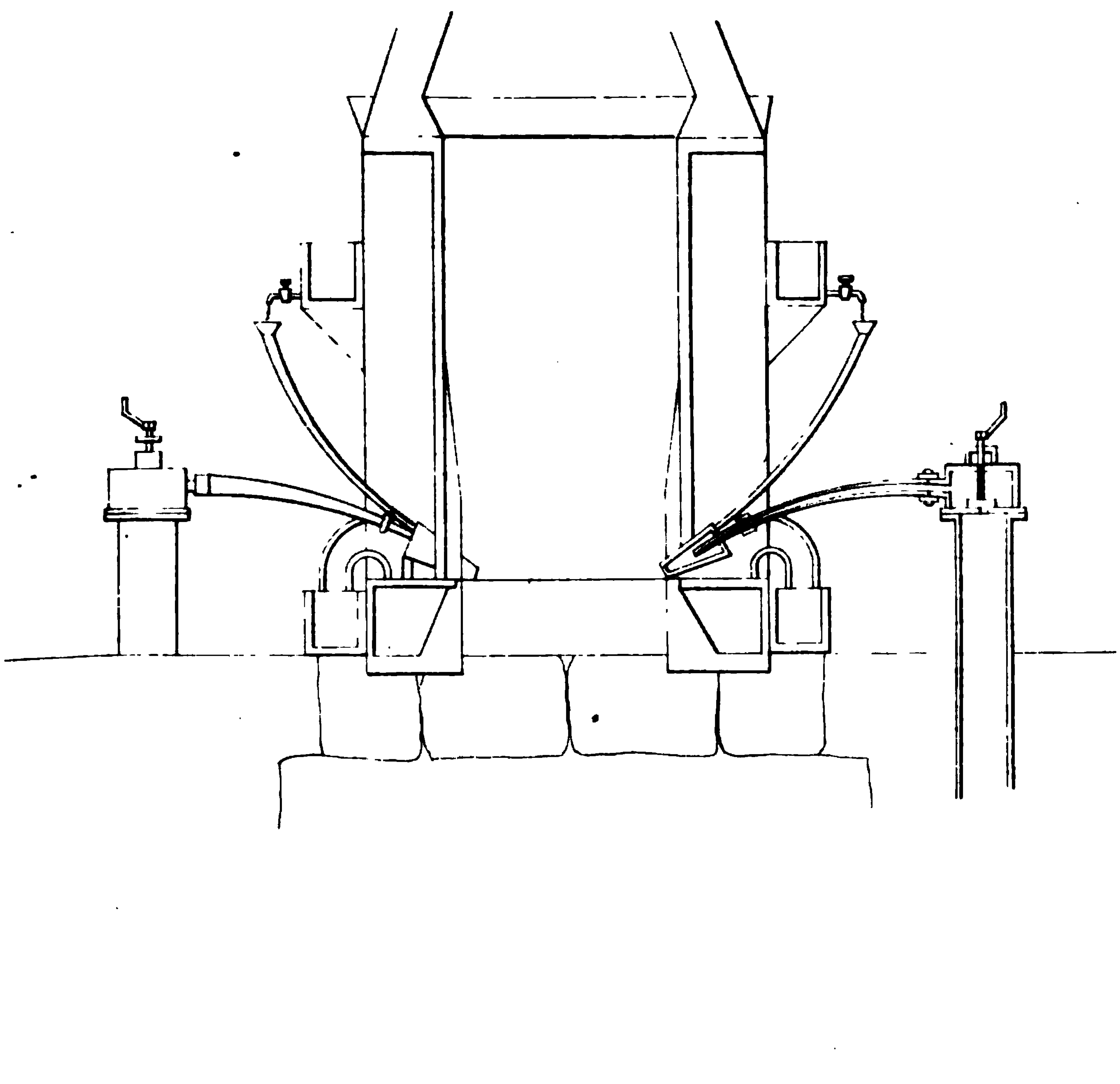
BLAST FURNACE



F. Bourquin & Co. Lith. Philada

Plate Nº 2

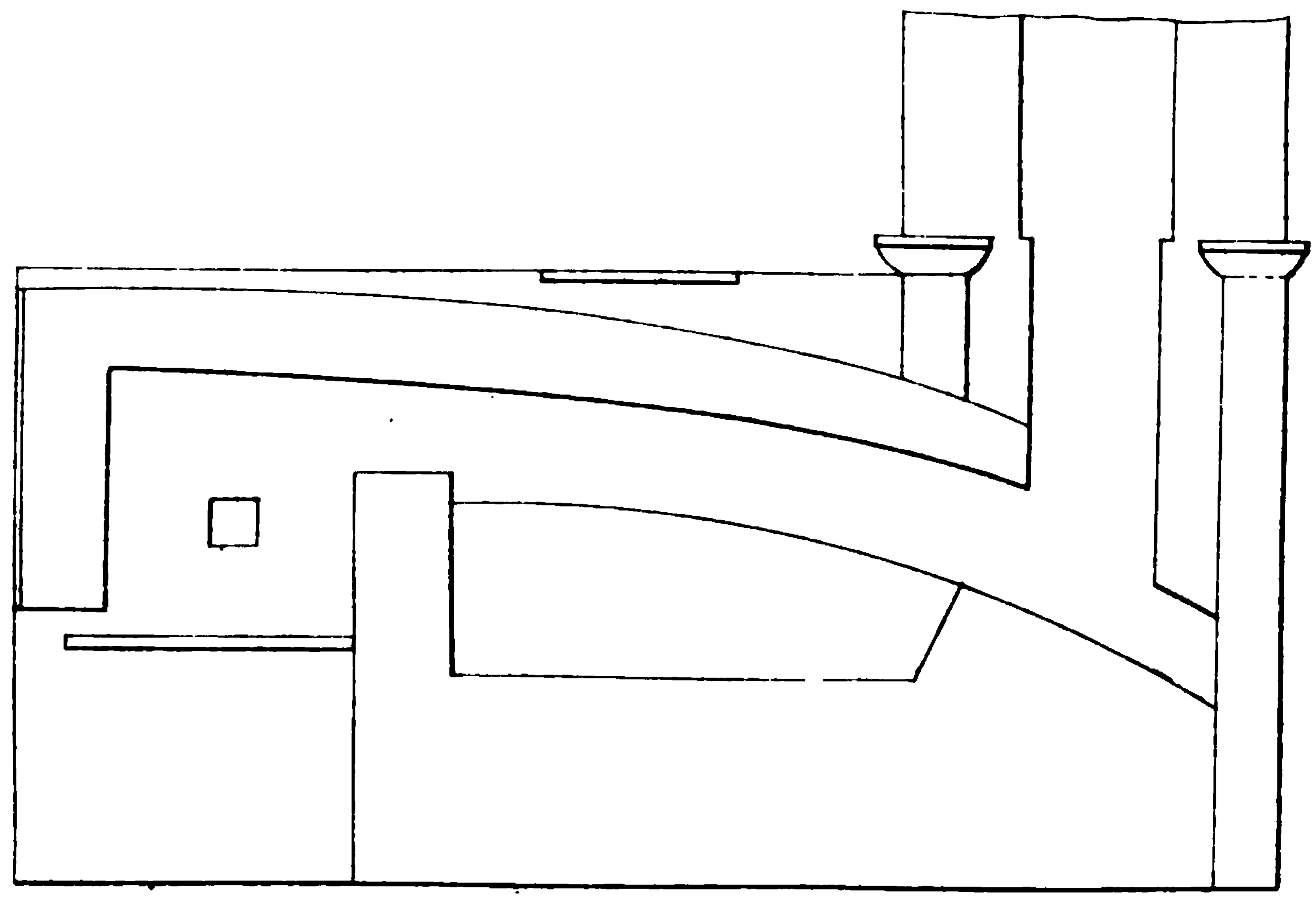
REFINING FURNACE



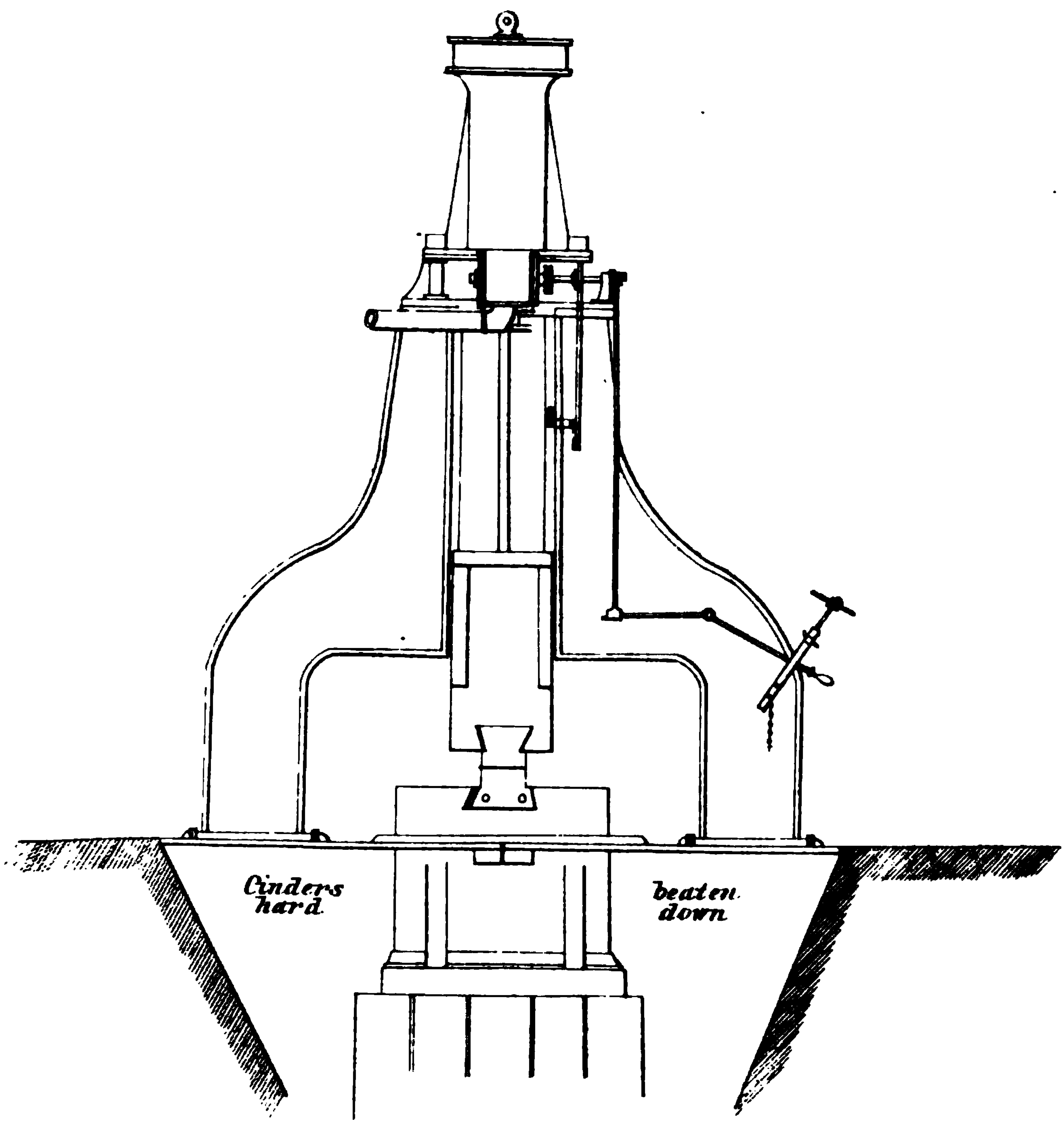
F. Bourquin & Cº Lith. Philada.

Plate No. 3.

REVERBERATORY FURNACE



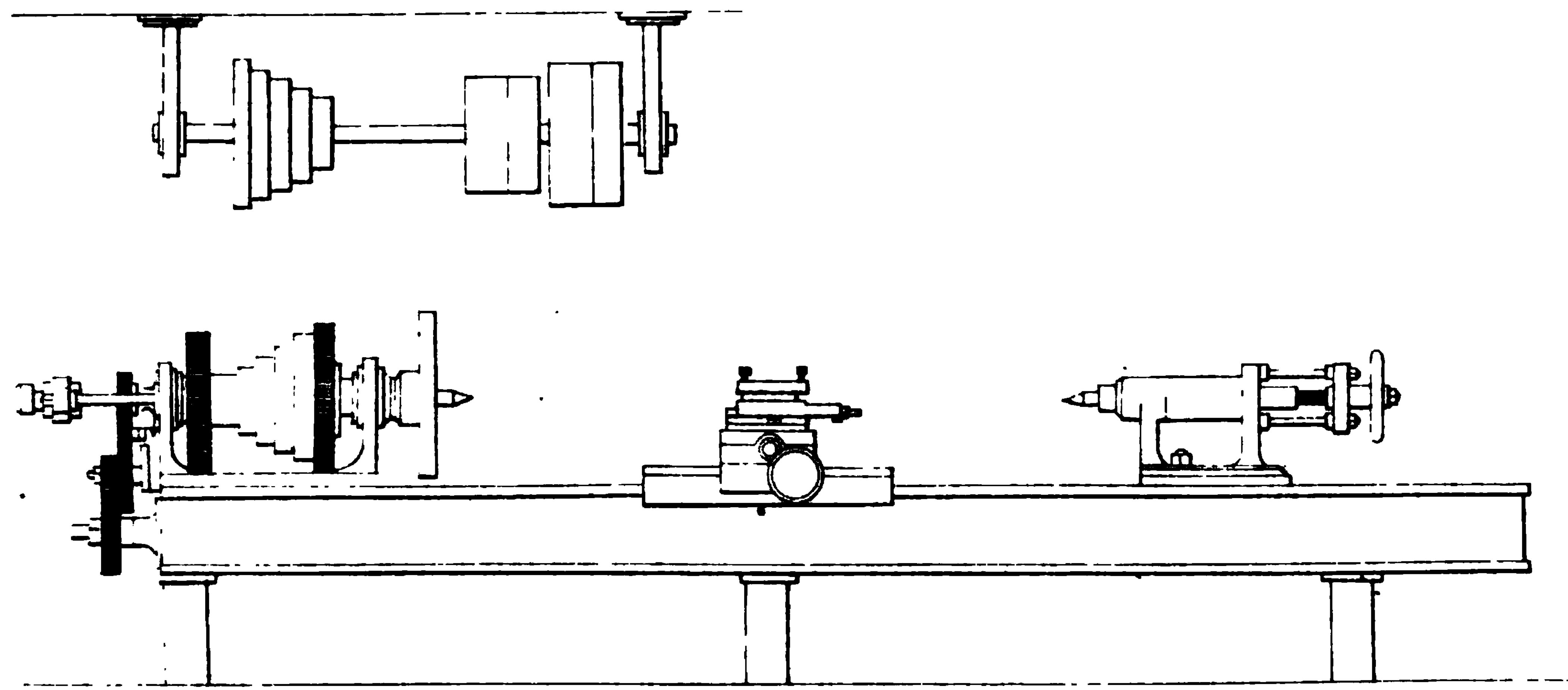
STEAM HAMMER




Scale ⅜ of an Inch to a foot

F. Bourquin & Cº Philada

## SLIDE & SCREW CUTTING LATHE

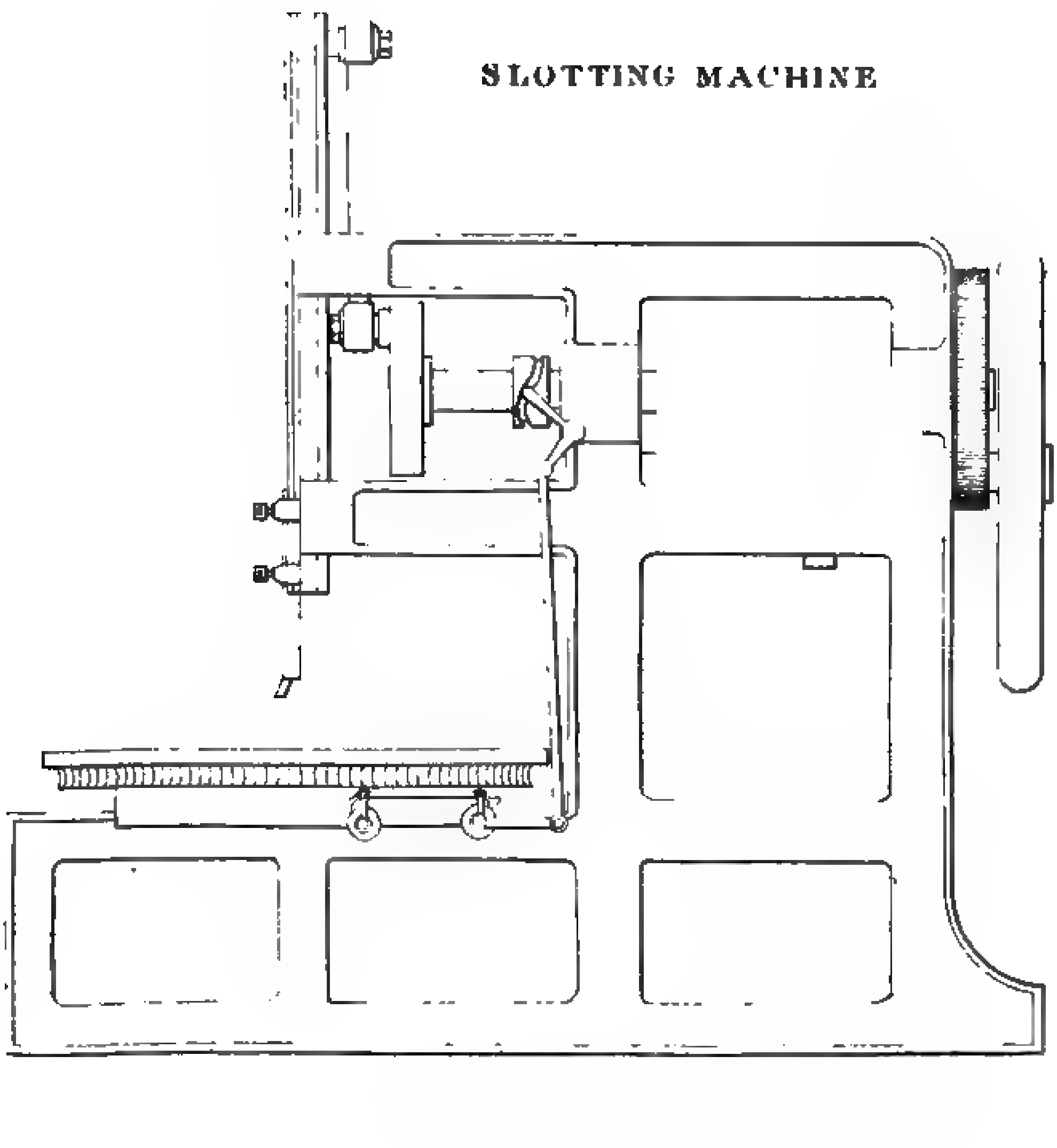


Scale 3/16 Inch – 1 Foot

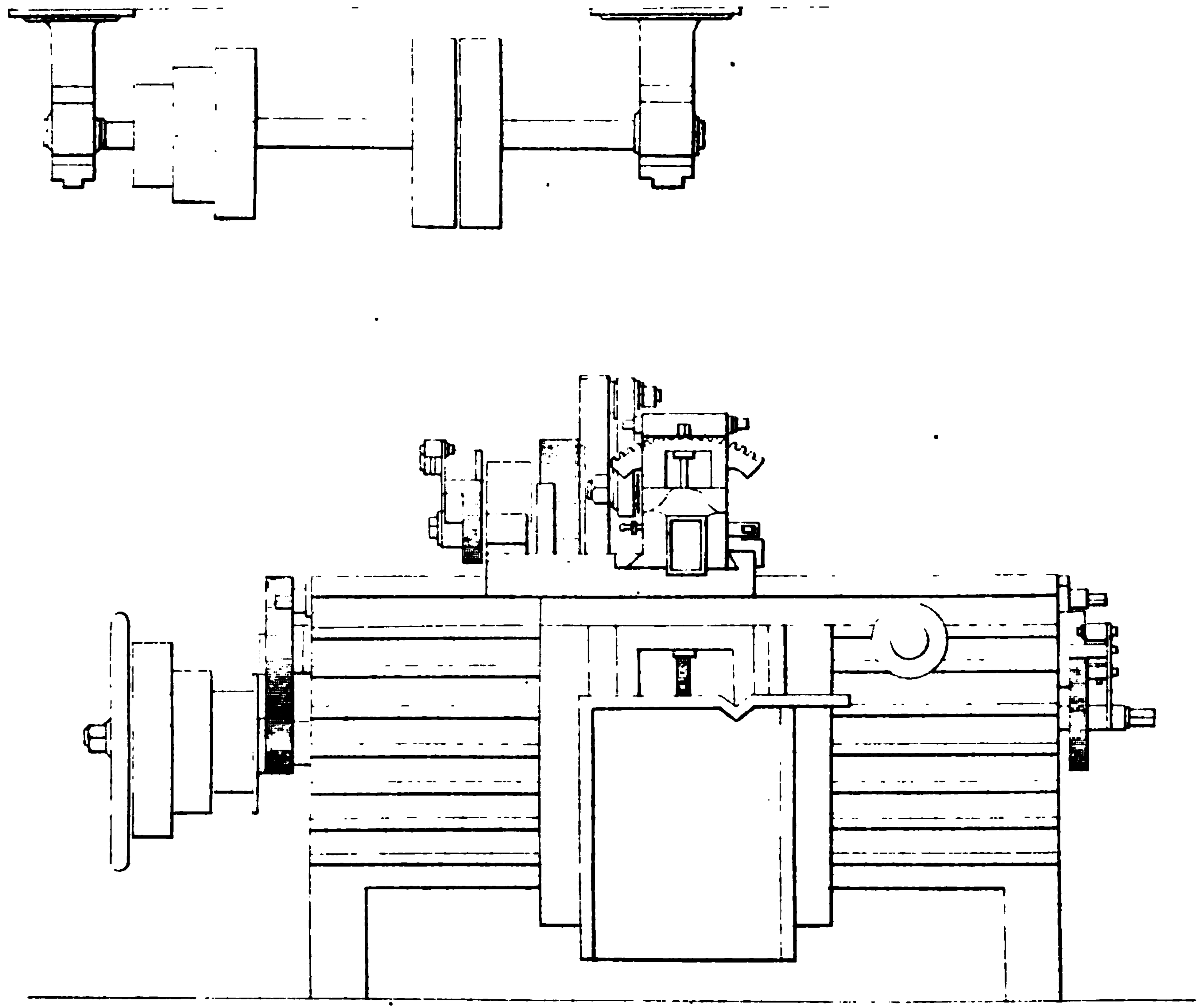
F. Bourquin & Co. lith. Philada.

Plate No 6

SLOTTING MACHINE



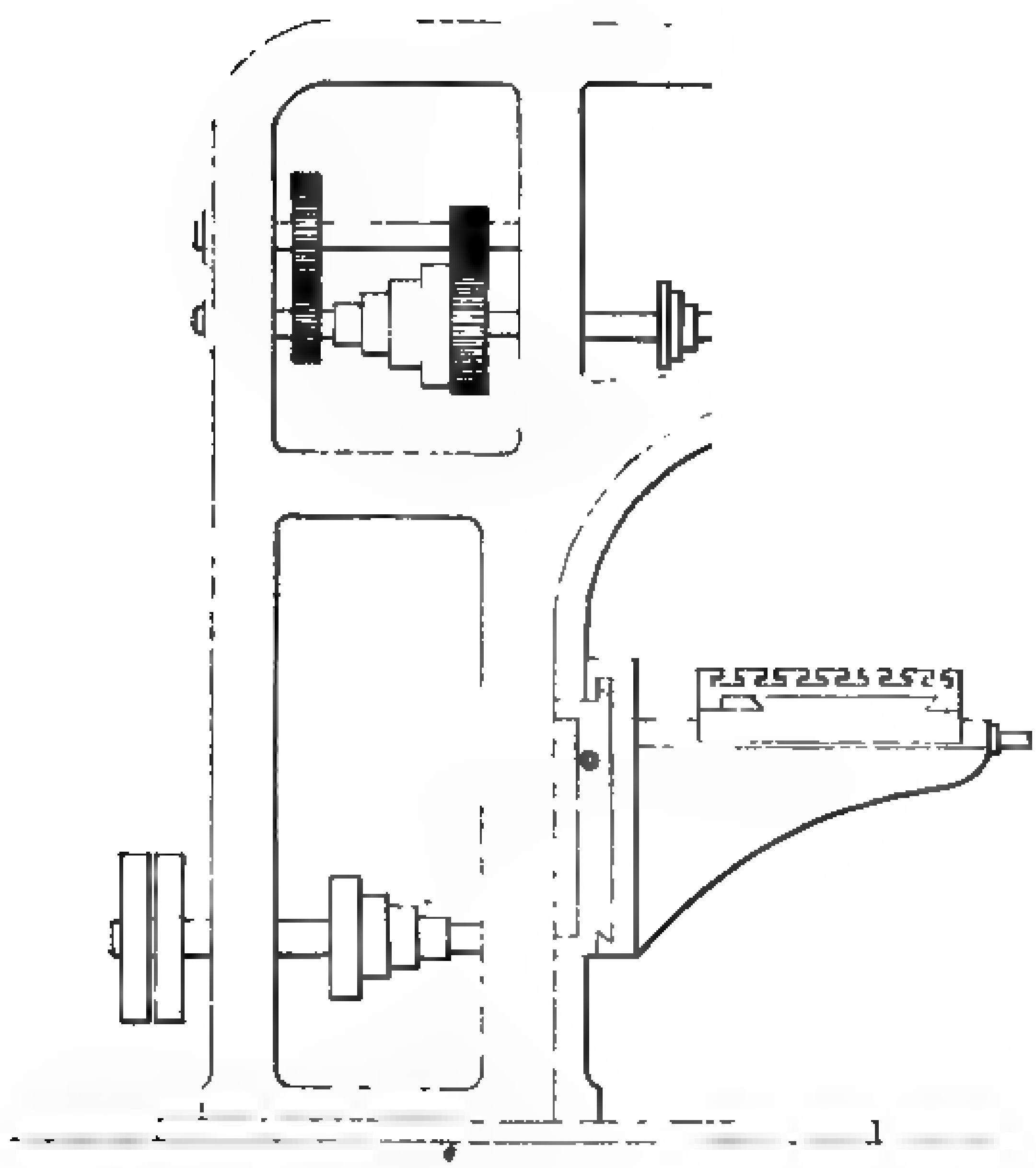
# SHAPING MACHINE.



Scale ⅔ In – a foot

F Bourquin & Co. lith. Philada

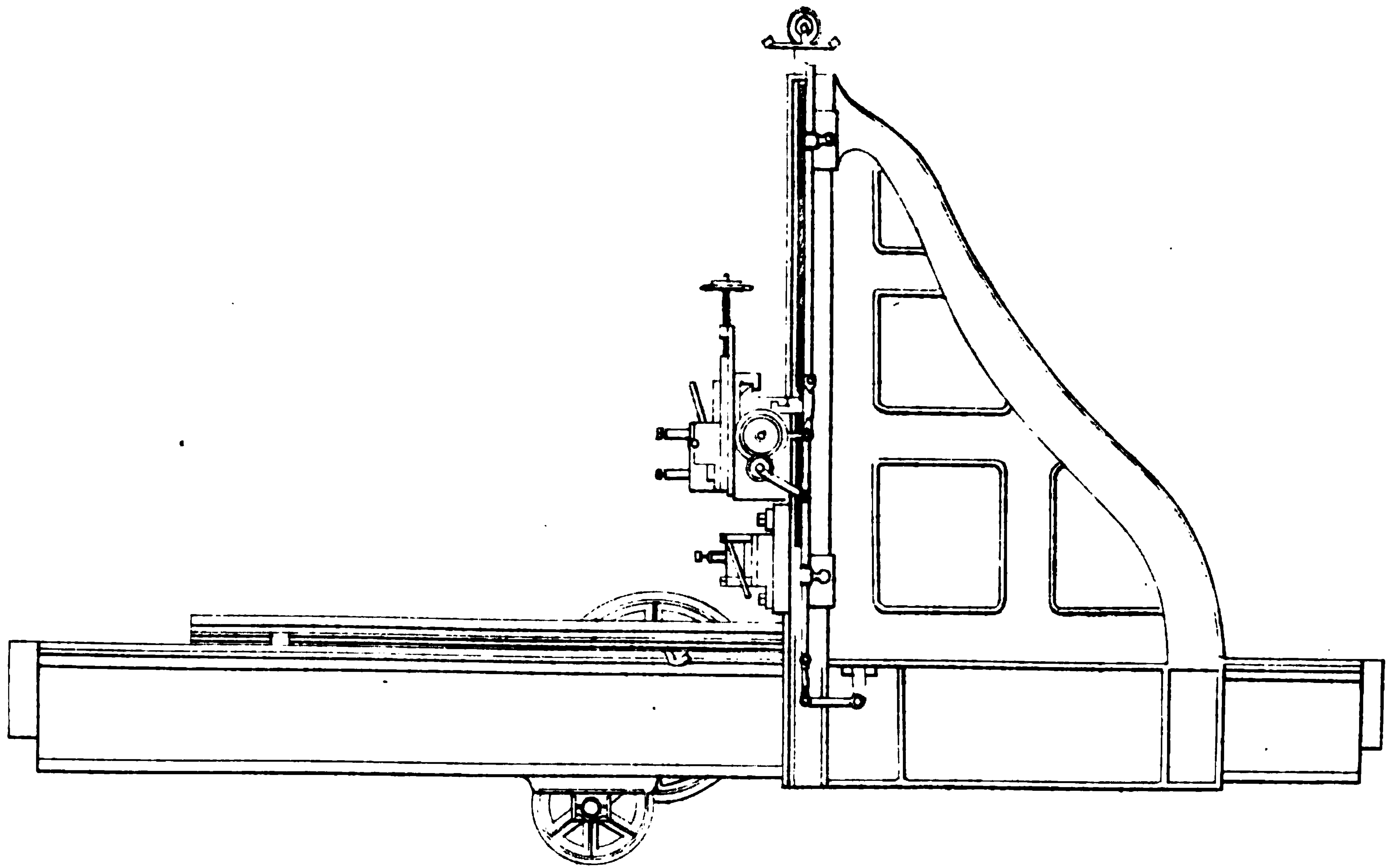
DRILLING MACHINE



Scale ½ an Inch to a foot

P Bourquin & Cº lith. Phila

PLANING MACHINE

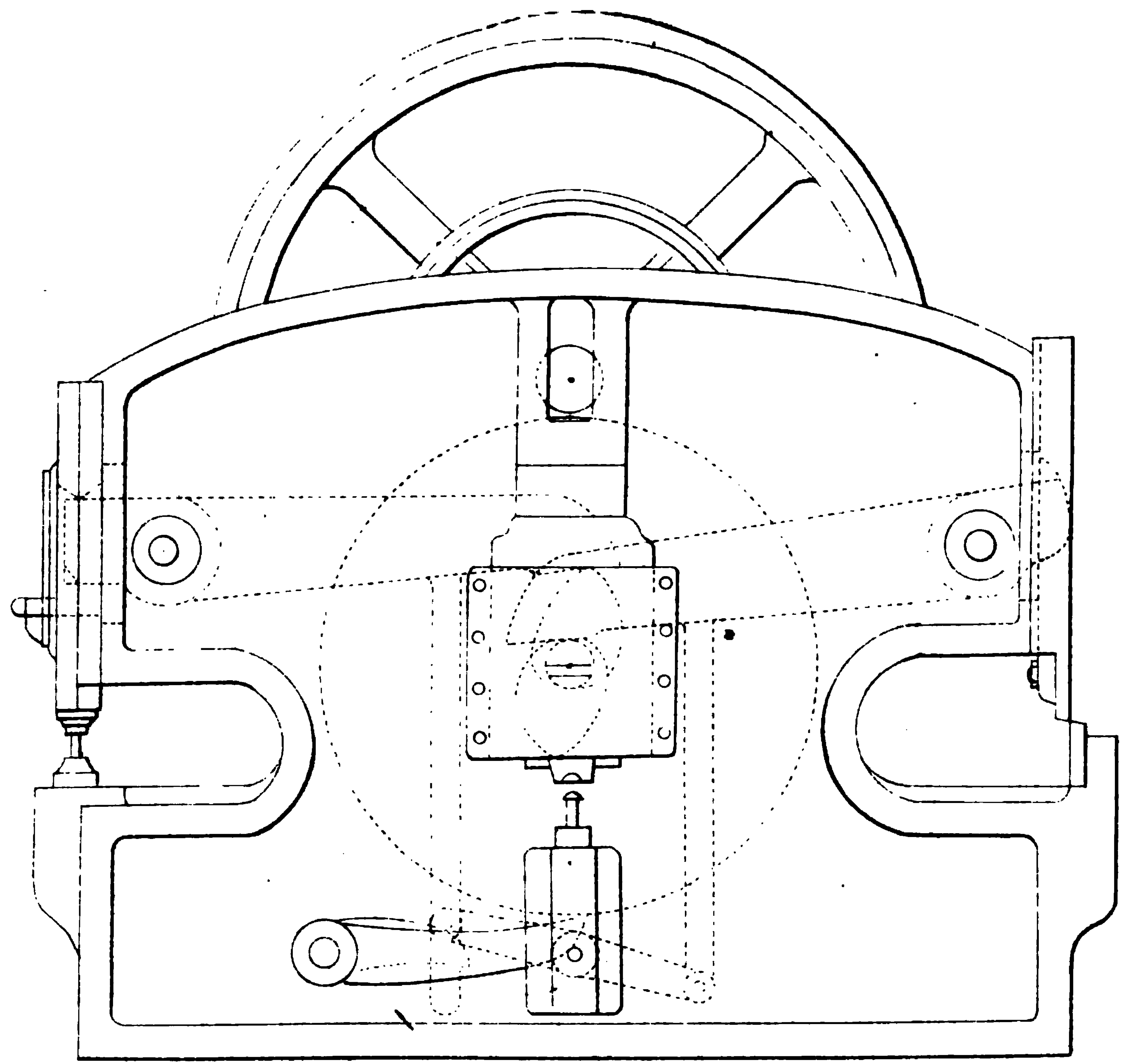


Scale 1/3 Inch – a foot

F. Bourquin & Co. Lith. Philada

Plate No 10

# PUNCHING, SHEARING & RIVETTING MACHINE



Scale 3/8 a foot

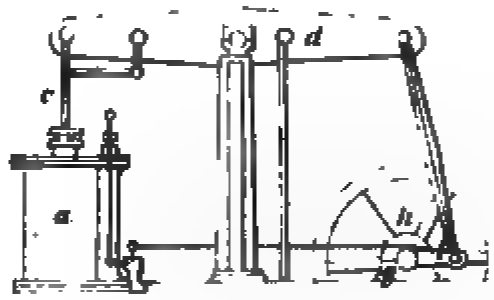
F. Bourquin & Co Lith Philada

Plate N II

## GENERAL ARRANGEMENT OF STEAM ENGINES

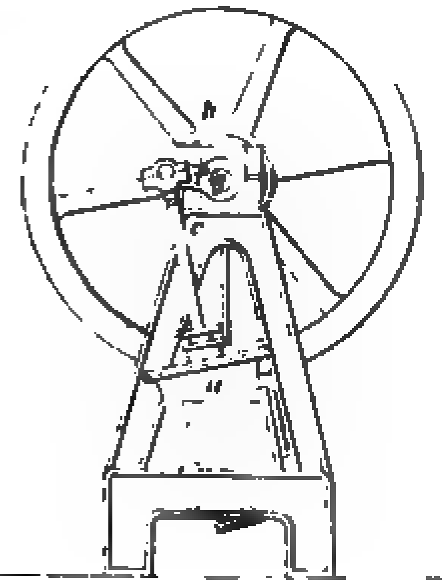
### CPumping Engine

### Beam Engine

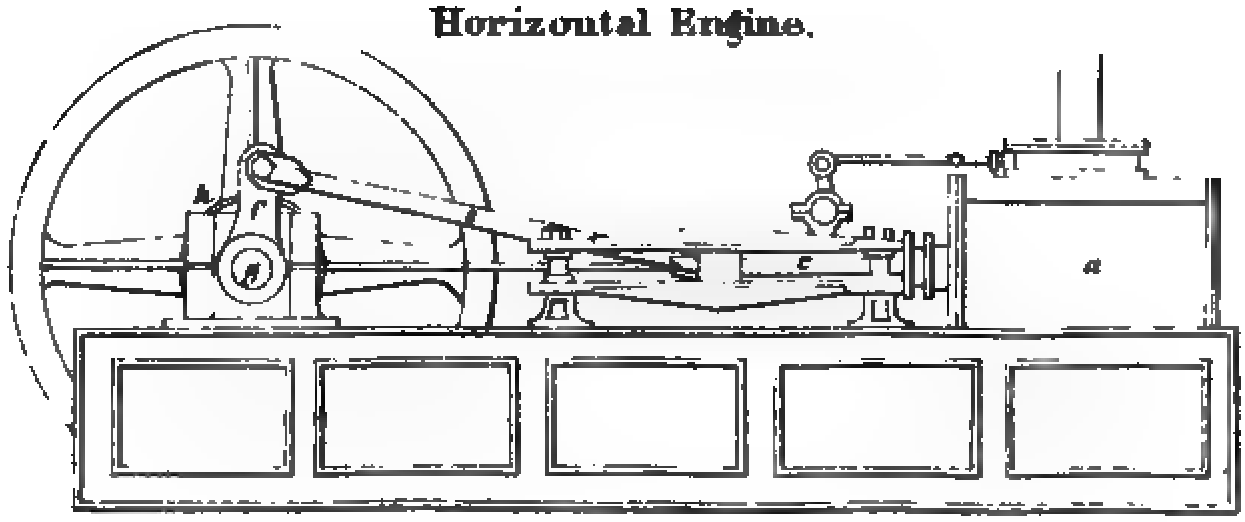


### Vertical Engine

### Oscillating Engine



### Horizontal Engine.



P Bourquin & C° Lith Philada

Plate No. 12

## VARIOUS FORMS OF GOVERNORS.

Fig. 1

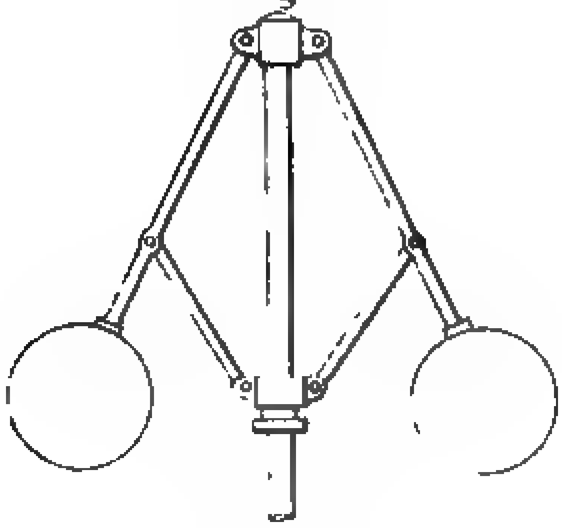


Fig. 2.

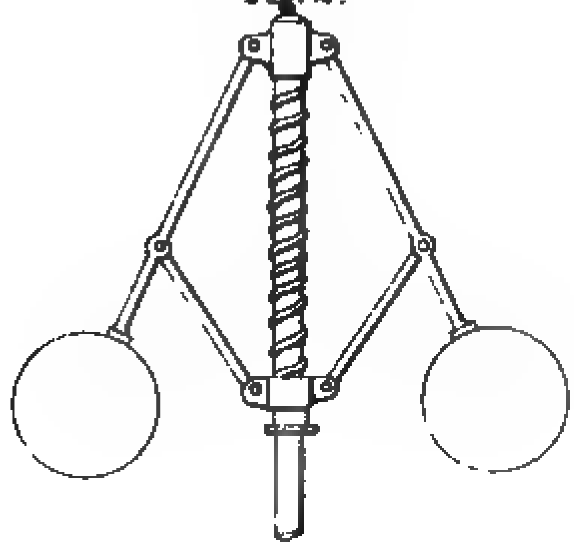


Fig. 4.

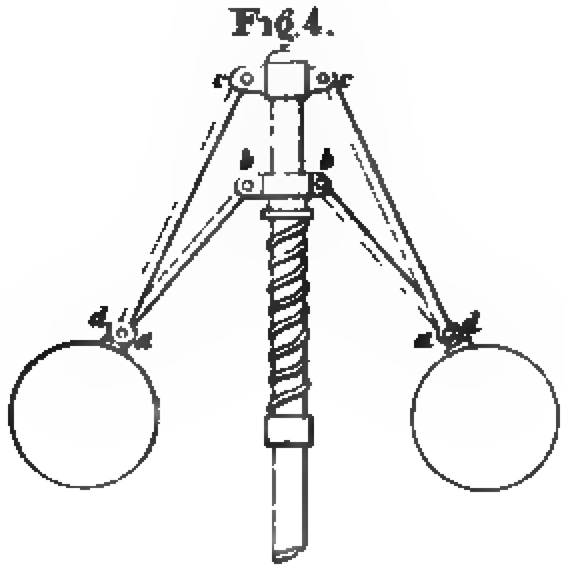


Fig. 5

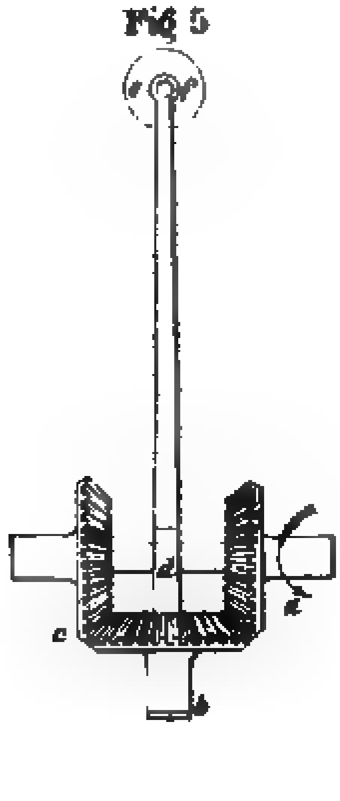
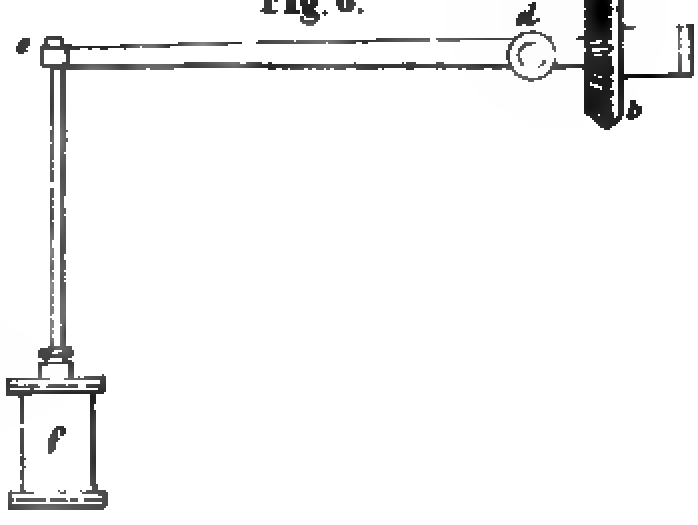


Fig. 6.



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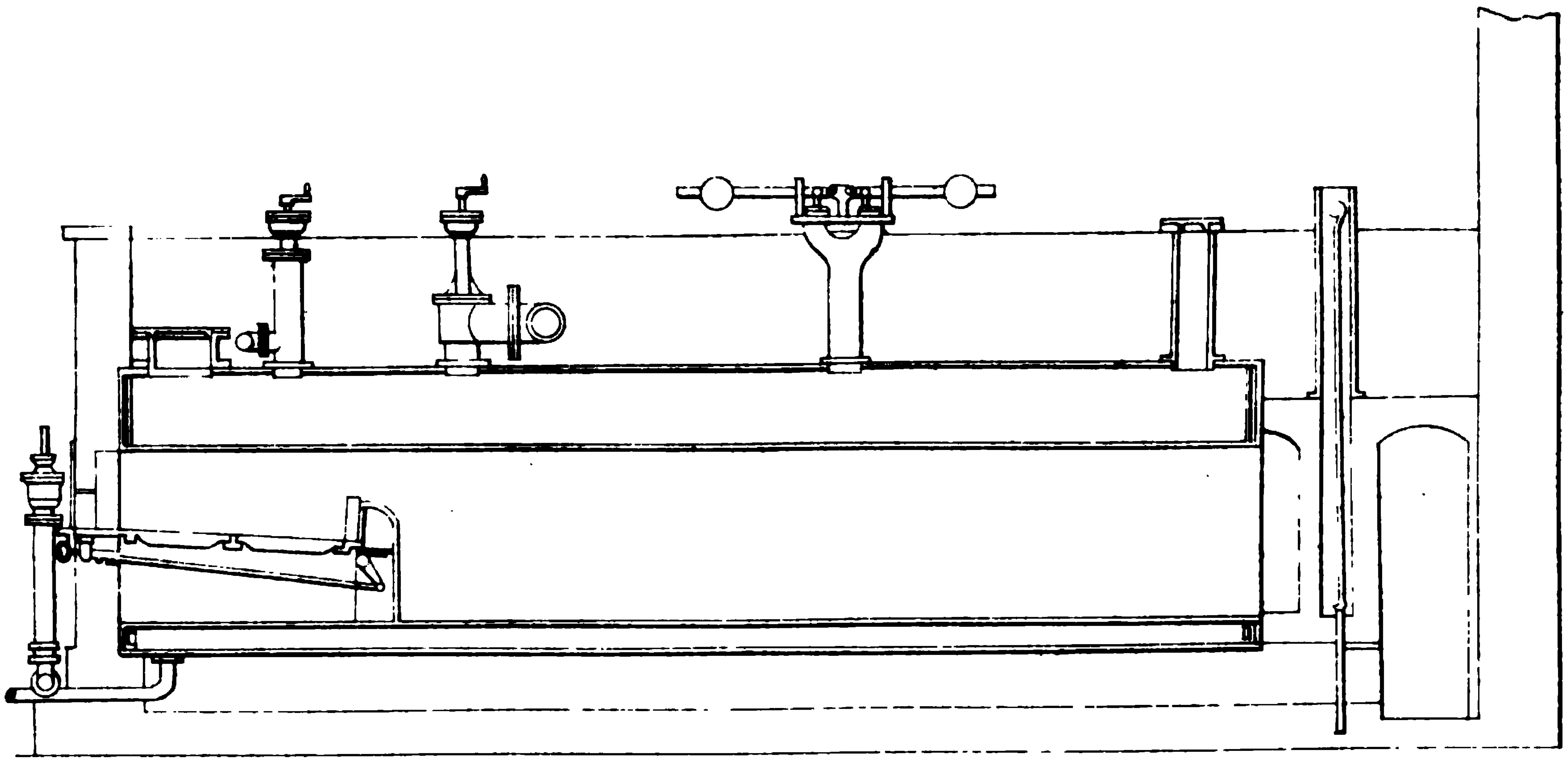
# CORNISH BOILER

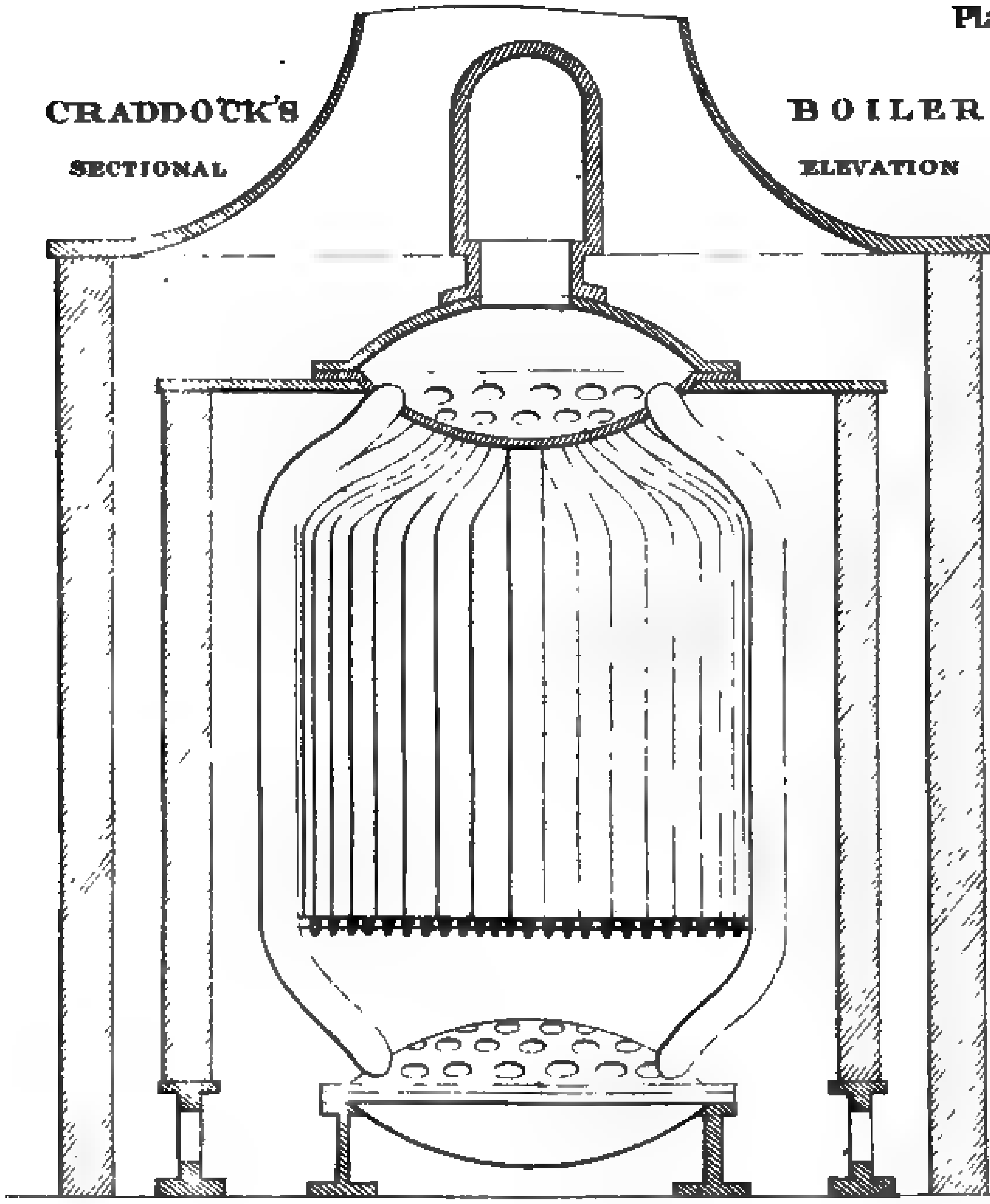
ERECTED AT THE SCARBORO WATER WORKS

THOMAS WICKSTEED ESQ M.I.C.E. ENGINEER



Scale ¼ Inch – 1 Foot

F. Bourquin & Co Lith. Philada.




SECTION.

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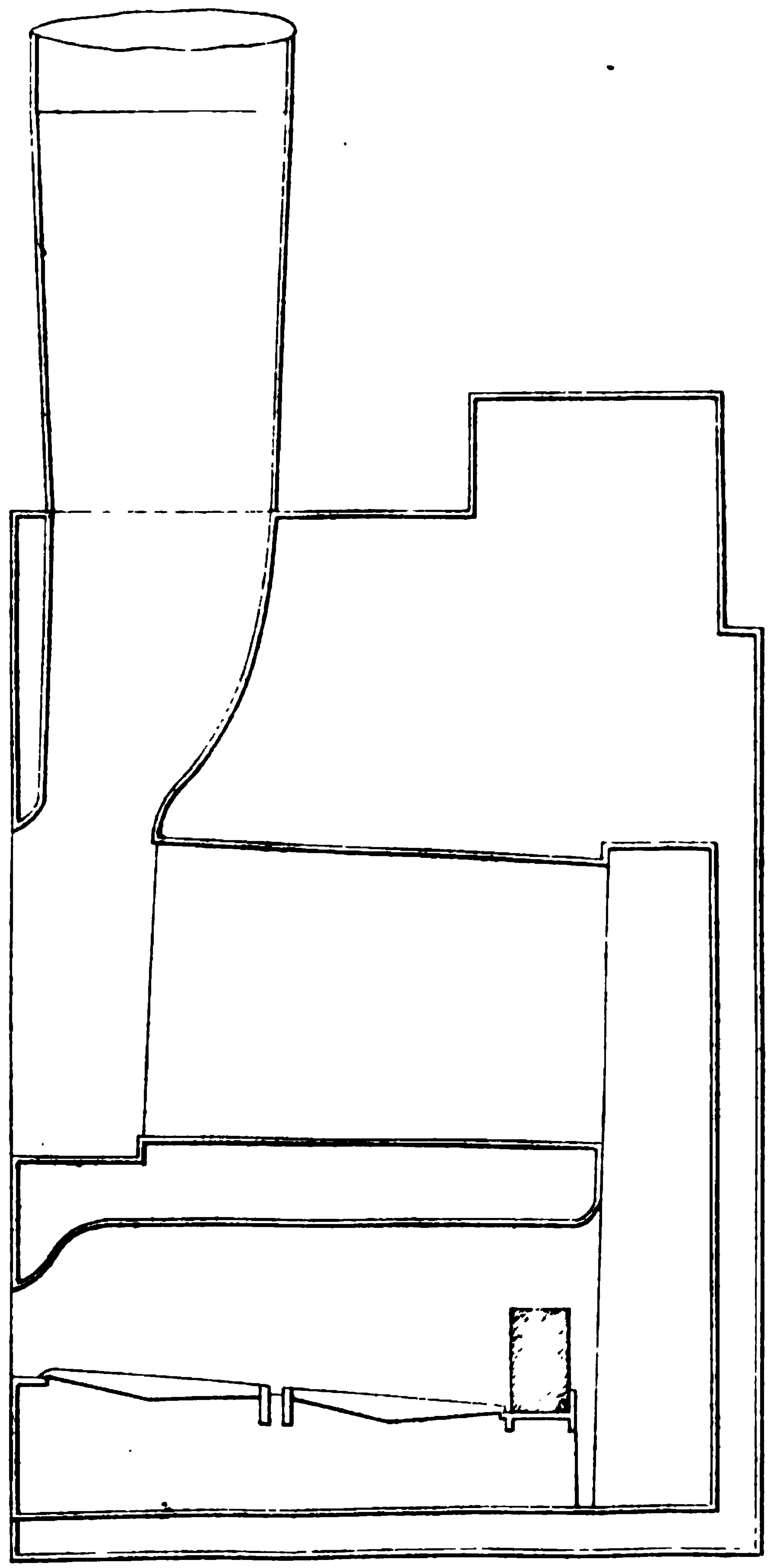
Plate No. 15.

## MARINE FLUE BOILER



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# MARINE TUBULAR BOILER

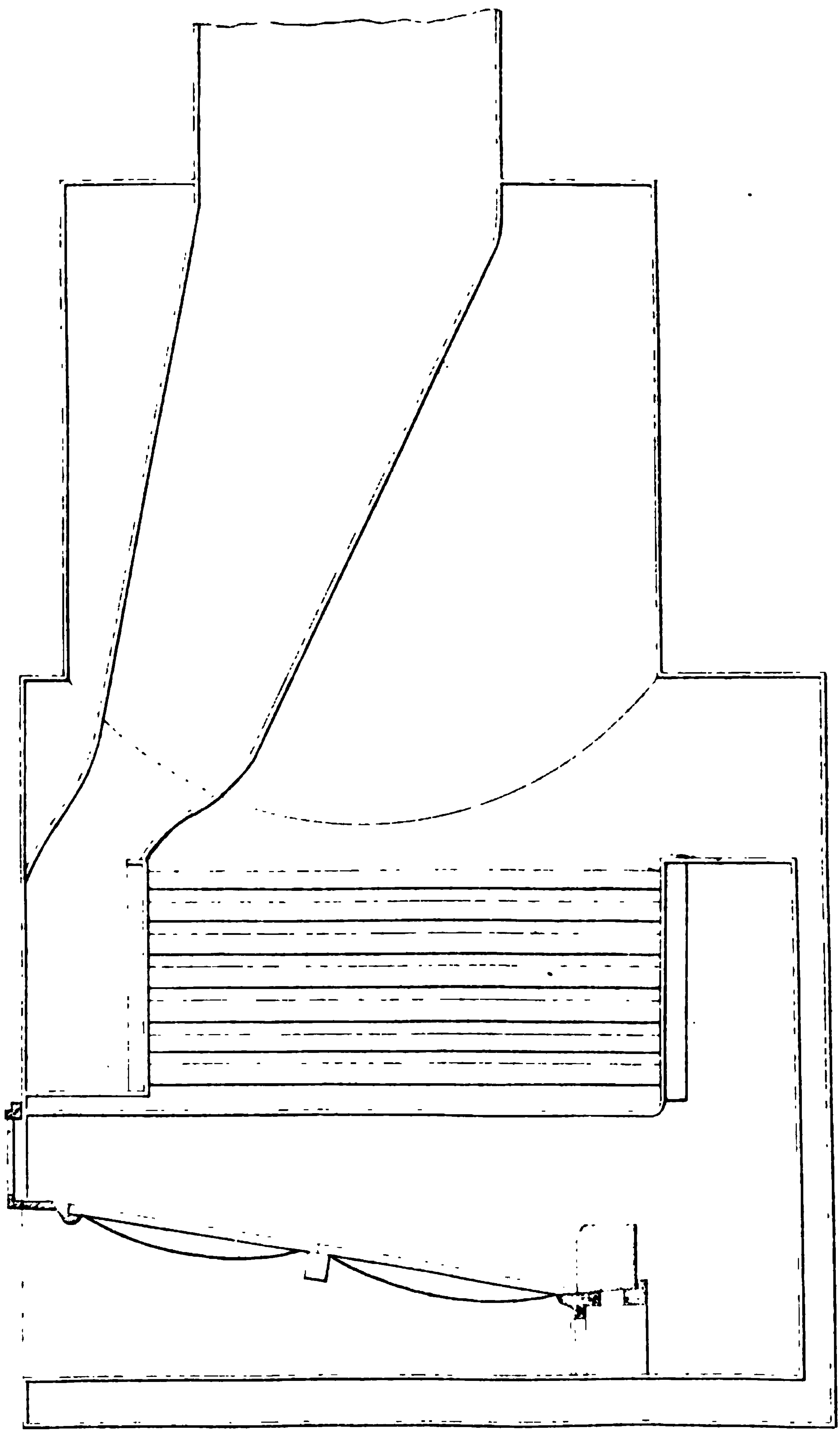

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Plate No. 17.

# GUMPEL'S PROPELLER.

Fig. 1.

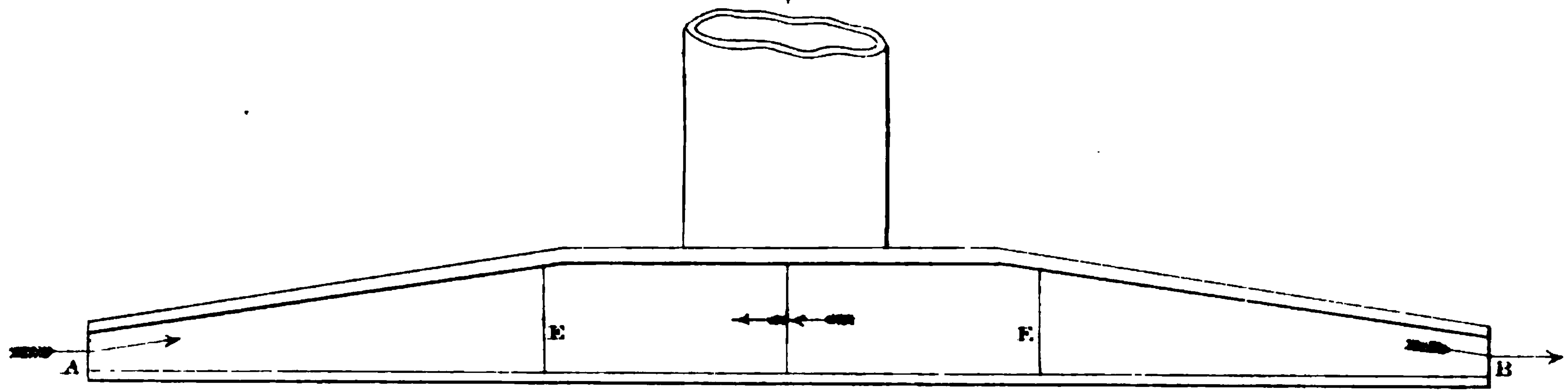
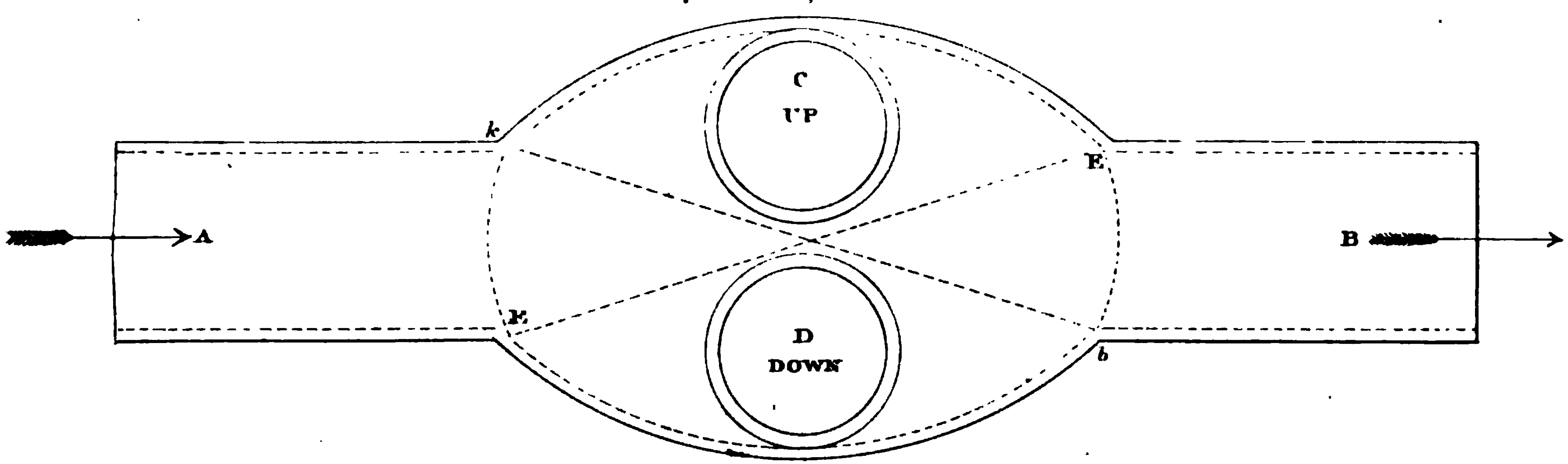



Fig. 2.



SIDE LEVER MARINE ENGINE. Plate No. 23.

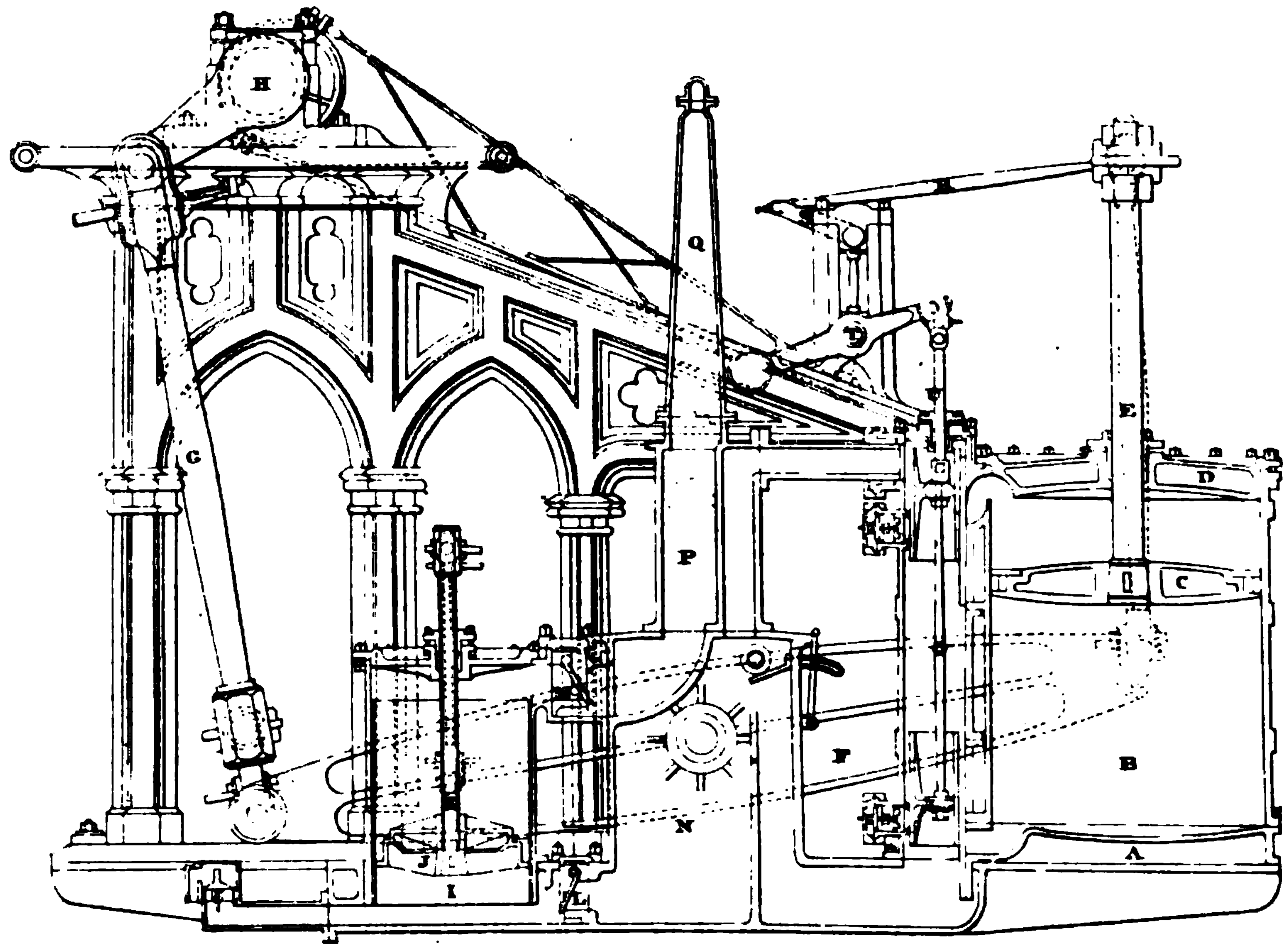



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Plate No. 25

EXPRESS ENGINE

MANUFACTURED BY MESSRS. ROBERT STEPHENSON & Co.

FOR THE

YORK NEWCASTLE & BERWICK RAILWAY

Plate No. 26

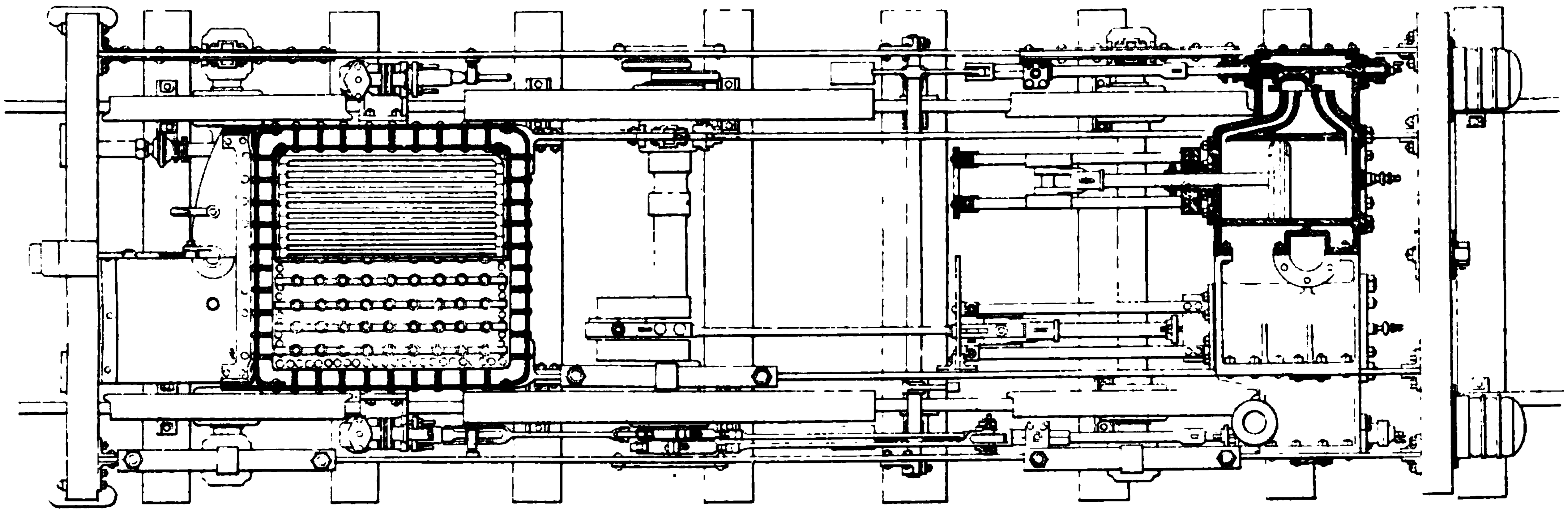
# EXPRESS ENGINE

MANUFACTURED BY MESSRS. ROBT. STEPHENSON & Co.

FOR THE

YORK NEWCASTLE & BERWICK RAILWAY

1848.



Scale of Feet

1 2 3 4 5 6 7 8 9 10 11

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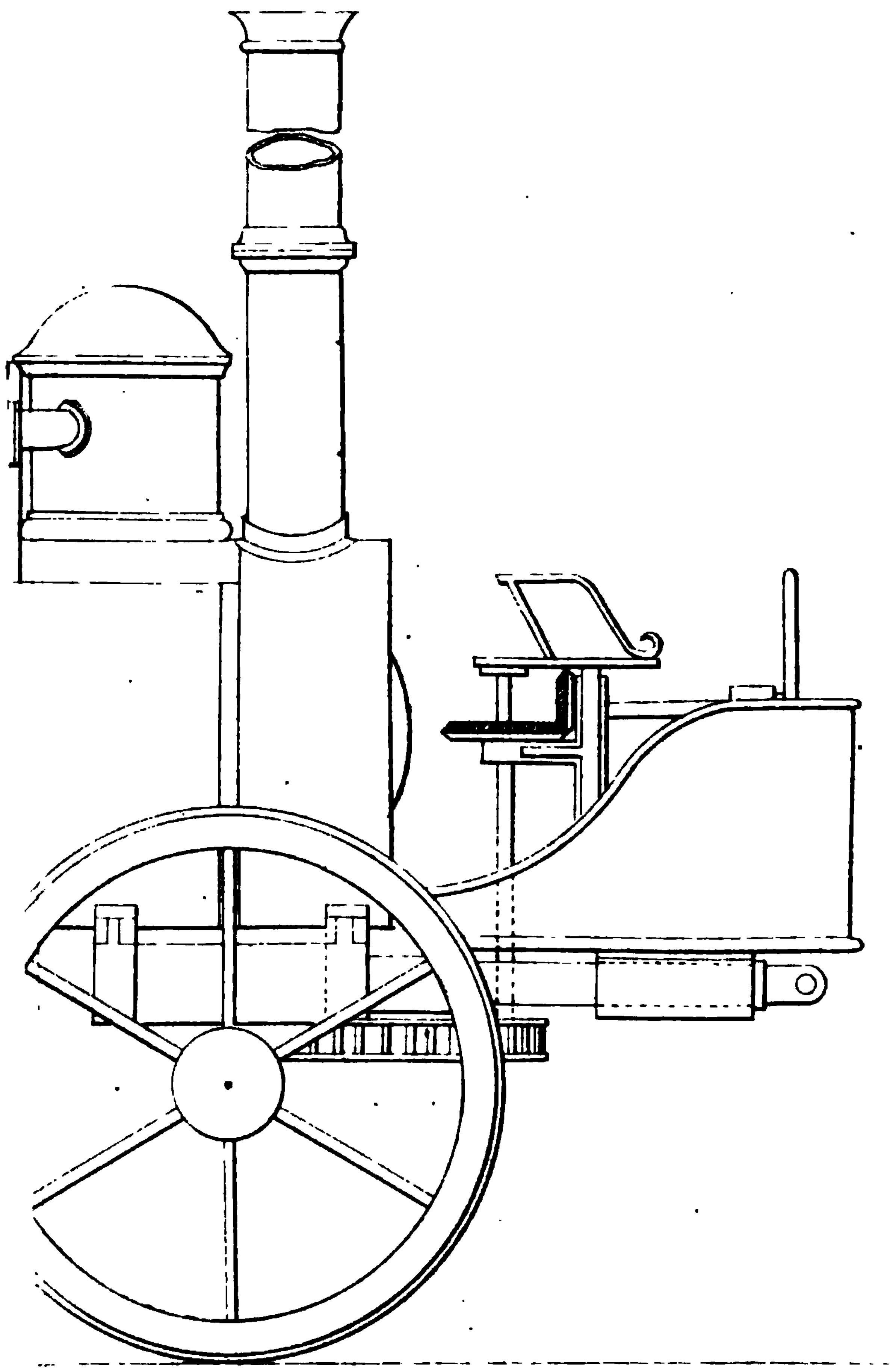
**\KE'S AGRICULTURAL LOCOMOTIVE**



·cale ½ Inch-1 Foot

Plate Nº 27.

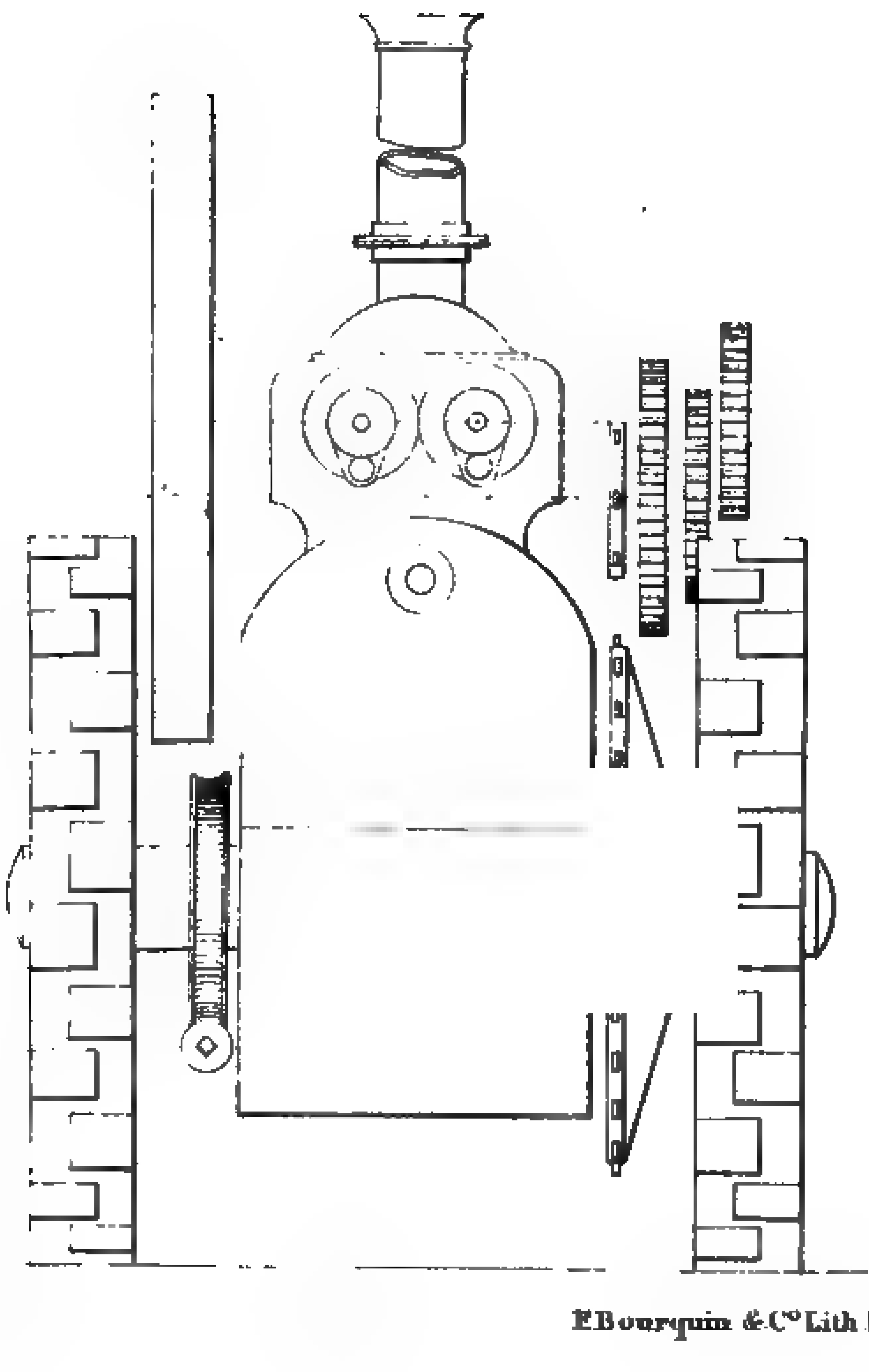


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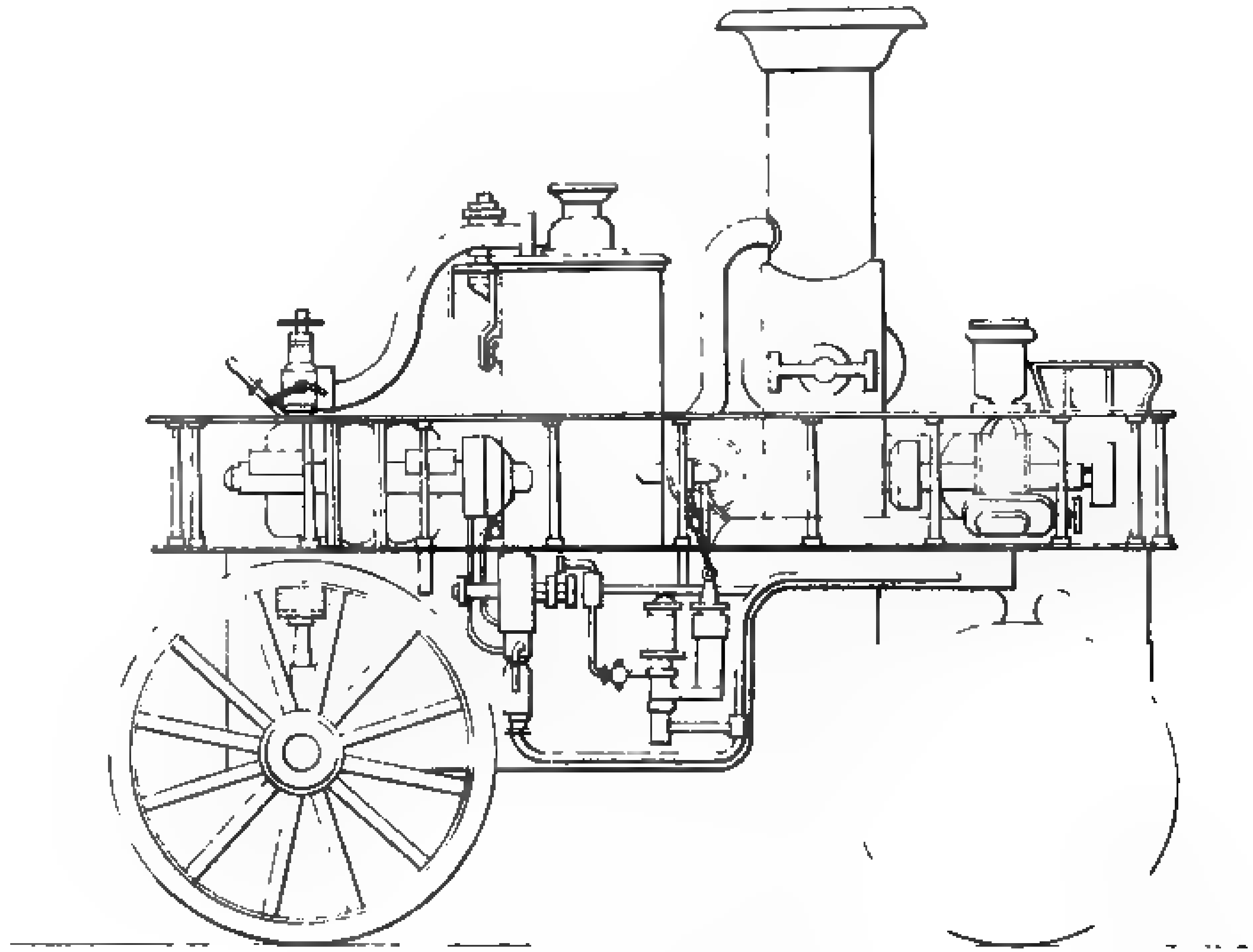
Plate №28

SILSBY, MYNDERSE & Cos STEAM FIRE ENGINE



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